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THE CLASSIFICATION OF EUROPEAN GLACIAL DEPOSITS.

When the "Superficial Formations" of Europe began to attract attention, geologists soon discovered that these could be naturally classed under two heads. The lower and therefore the older deposits were characterized especially by their confused and tumultuous appearance, while the overlying younger formations showed a more or less orderly arrangement in layers or beds. The confused accumulations of the lower group were generally believed to be the products of some kind of cataclysmic action—perhaps, as some thought, the Noachian Deluge, or, according to others, mysterious debâcles and waves of translation, caused, it was imagined, by titanic disturbances of the earth's crust. By common consent the tumultuous deposits came to be known as *Diluvium*, while the overlying bedded accumulations were termed *Alluvium*, and were attributed to the action of water under those normal conditions of the surface that now obtain. It is unnecessary to ask why the diluvial explanation of the drift-phenomena ever commended itself to competent observers. Perhaps geologists had not yet quite freed themselves from the influence of their predecessors, whose heroic attempts to cut Gordian knots figure so prominently in the early literature of the science. One thing is certain that the principal advocates of the diluvial doctrine were ignorant of modern glacial action, and, with a few notable exceptions, had only the

most cursory acquaintance with the phenomena which they sought to explain. That their diluvial notions should have appeared reasonable to themselves and satisfactory to their disciples, who knew less, need not surprise us. Even in our own day we may see how the same doctrines can appeal to one who has merely a superficial literary acquaintance with the subject. The copious outpourings of Sir H. H. Howorth, if they have neither aided nor retarded the advance of glacial geology, have at least shown what a large field of profitless labor the pseudo-scientific wise men of Gotham have hitherto neglected to cultivate.

Long after the various diluvial hypotheses had been abandoned, and the glacial origin of the so-called *Diluvium* had been recognized, the deposits included under that term continued to be lumped together. Certain accumulations in mountainous countries, it is true, were believed to be moraines of local glaciers, but the "great northern drift" of the European lowgrounds was looked upon as iceberg-droppings, and the whole diluvial formation was considered one and indivisible. Even after the dressed rock-surfaces and bowlder-clays of lowland regions had been assigned to the action of glaciers and ice-sheets, geologists continued in the belief that the Diluvium was the product of one protracted period of cold conditions. For a long time the only classification attempted was the subdivision of the drift series into morainic and marine accumulations. No one had as yet suspected the existence of what are now known as interglacial beds. Some of these, it is true, had been examined and described, but their true relation to the glacial deposits had not been recognized. Thus, up to a recent date, geologists—whatever their views might be as to the subglacial or submarine origin of the "drift" as a whole—did not doubt the unity of the Glacial Period. It was in Switzerland that the true meaning of interglacial deposits was first ascertained. Morlot, Heer, and others have put on record the observations which led them to conclude that the Alpine Lands have been subjected to two successive glaciations—the one separated from

the other by a prolonged epoch of erosion and accumulation, under climatic conditions somewhat similar to those now existing. Meanwhile, geologists in Britain had discovered that the drift deposits formed a triple series—namely, (*a*) lower bowlder-clay, (*b*) middle sand and gravel, and (*c*) upper bowlder-clay. And some were inclined to consider this grouping as roughly corresponding to the threefold arrangement of the Swiss deposits, and to infer that in the British area there had been two glacial epochs separated by an interval of submergence, when somewhat milder climatic conditions prevailed. In Germany, likewise, an "upper" and a "lower" Diluvium had been recognized long before the true significance of these groups dawned upon geologists. As observations increased it was found that here and there, in Scotland and elsewhere, beds of peat and fossiliferous fresh-water deposits appeared intercalated in bowlder-clay, or separating a lower from an upper bowlder-clay. By those who were of opinion that bowlder-clay is a ground moraine these intercalated beds were looked upon as evidence of glacial oscillations, of no great magnitude. It was supposed that the former glaciers and ice-sheets were subject, like their modern representatives, to temporary movements of advance and retreat. During a time of retreat vegetation spread over the ground vacated by the ice, and when the next forward movement took place the glaciers reoccupied the area invaded by plants, and buried the old soils under fresh accumulations of glacial débris. The upholders of the iceberg origin of the drifts did not attempt to account for the appearance of such intercalated fresh-water beds. It was easier to belittle their importance or to ignore them altogether. The deposits in question have now been encountered, however, in so many formerly glaciated areas that it is no longer possible to pass them by as accidental occurrences that may in time be somehow or other explained away. Their true significance is now the only question in dispute. Do they indicate mere local and temporary movements of glacial retreat and advance, or are they relics of long-continued milder conditions occurring between separate and distinct glacial epochs?

At first sight the former view appears the more reasonable, and to those who have never studied the phenomena accompanying interglacial deposits, it naturally has a special attraction. It is so simple, and so much in accordance with what is actually known of modern glacial action, that those who hold it may be excused for wondering why it is not generally accepted. We are referred to the glaciers of New Zealand which descend into the region of tree-ferns, and to certain glaciers of the Himalaya and Alaska with their tree-covered moraines, and are asked to consider how readily in those regions vegetable débris may become entombed in glacial accumulations. But there is no need to go so far abroad for similar phenomena. Even in the Alps in our day glaciers have advanced and buried trees and vegetable soil under their moraines. Unfortunately, however, none of these cases helps us to account for the interglacial beds of temperate Europe. If the latter never yielded other than Arctic-alpine plants something might be said for the explanation in question. During the climax of the glacial period, when the Scandinavian "inland-ice" invaded the low grounds of middle Europe, those low grounds supported an Arctic-alpine flora. It is obvious, therefore, that when temporary retreats and advances of the ice-front took place, the only relics of plant-life that were likely to be preserved in glacial deposits would be Arctic forms. But although such are not wanting at certain horizons in the glacial series, yet the most conspicuous interglacial beds are charged with the relics of a flora and fauna which could not possibly have flourished in the immediate vicinity of a great ice-sheet. Indeed, the interglacial beds, traced at intervals from Holstein through the heart of Germany to central Russia, contain a flora indicative of more genial conditions than are now met with in the same regions. One may feel quite sure that when the low grounds of middle Europe were clothed with such a flora, and tenanted by elephants and other large herbivora, no great Scandinavian ice-sheet could have existed. There is no reason to doubt, in short, that the snow-fields and glaciers of interglacial Europe were not more prominent than those of the Europe of today. And yet the

interglacial deposits referred to rest upon and are covered by glacial and fluvio-glacial accumulations. Here, then, we have to do not with mere local oscillations of an ice-front, but with great climatic changes extending over protracted periods of time.

But this is not all,—the long persistence of interglacial conditions is further shown by the amount of denudation and valley-erosion accomplished during interglacial epochs. The best examples I can cite are those described by Professor Penck and others as characteristic of the Alpine Lands. In the valleys descending to the north three conspicuous gravel-terraces may be noted, rising one above the other. The highest displays an average thickness of about 100 feet—its upper surface being some 250 feet above the level of the present rivers. The second terrace (eighty feet or so in thickness) rests like the former upon solid rock, and its upper surface is 130 feet or thereabout below that of the older terrace. The third and lowest terrace, occurring inside the preceding, rests also upon solid rock, and its upper surface is some 125 feet below that of the second terrace. Each of these terraces is of fluvio-glacial origin, and directly connected with a separate series of glacial moraines. Obviously the tale they tell is one of glacial accumulation and interglacial erosion. After the formation of the highest terrace the glaciers retreated, and fluvio-glacial accumulation ceased. The rivers then slowly dug their way down through the fluvio-glacial gravels (100 feet thick) and, thereafter, proceeded to excavate the solid rock to the depth of another 100 feet at least. Thereafter ensued a return to glacial conditions, and over the newly excavated valley was accumulated another sheet of gravels reaching an average thickness of eighty feet. Once more the glaciers retreated, accumulation ceased, and valley-erosion was resumed, the rivers cutting down through the second series of gravels into the solid rock as before, which they trenched to a depth of sixty or seventy feet. Then a third advance of the glaciers took place and a corresponding series of fluvio-glacial gravels was deposited—the upper surface of which now rises

much beyond the reach of the greatest river-floods of today. Similar evidence of interglacial erosion is met with in many other mountain-regions of middle Europe—in the Carpathians, the Riesengebirge, the Black Forest, the Vosges and central France. In the last-named region the evidence shows that during the time that separated two glacial epochs the rivers dug out valleys some 900 feet in depth.

Such are some of the facts which have led many observers to believe in the periodicity of glacial action. There are several other lines of evidence that lead to the same conclusion, but it is needless to discuss these here as I have treated them more or less fully elsewhere. All that I shall attempt at present is to sketch in outline the general succession of glacial and interglacial horizons which can be more or less clearly made out in Europe. To avoid confusion I shall give to each of these horizons a separate name.

I. SCANIAN.

The earliest glacial deposits of northern Europe occur in Skâne—the old division of southern Sweden—hence the provisional name I suggest. These indicate the former existence of a great Baltic glacier which overflowed the southern part of the Scandinavian peninsula from southeast to northwest. No glacial deposits have been recognized on this horizon elsewhere in northern Europe. It is most probable, however, that the Arctic-shell beds of Norfolk known as the Chillesford Clay and Weybourn Crag belong to this stage. To the same horizon I assign the first glacial epoch of which we have evidence in the Alpine Lands. At this stage the glaciers of that region filled all the mountain-valleys and in many cases deployed upon the "Vorländer," where their terminal moraines and associated fluvio-glacial gravels are still conspicuous. To the same epoch ought probably to be referred the ancient Diluvium of the plateaux of central France. According to Penck the snow-line in the Alpine Lands must have been depressed some 4000 feet below its present level.

II. NORFOLKIAN (OR ELEPHAS-MERIDIONALIS STAGE).

This stage is typically represented in northern Europe by the well-known "Forest-bed Series" of Norfolk. During the preceding epoch the North Sea was probably not less extensive than it is today—it even encroached upon what are now the maritime tracts of East Anglia. The "Forest-bed Series" of Norfolk points to the retreat of the North Sea from the southern area of that basin. Britain was at that time joined to the Continent and enjoyed a climate not less temperate than the present. The mammalian fauna included *Elephas meridionalis*, *E. antiquus*, *Hippopotamus*, *Rhinoceros etruscus*, *Machærodus*, etc. In the Alpine Lands the same stage is represented by the lignite-beds of Leffe, etc. (N. Italy), containing *Elephas meridionalis*, *Rhinoceros leptorhinus*, etc., and a flora indicative of more genial conditions than are now experienced in the valleys where those deposits occur. On the same horizon are the interglacial beds of Hötting in the valley of the Inn at Innsbruck—the remarkable flora of which similarly testifies to a warmer climate than the present. The so-called Upper Pliocene deposits of France, such as those of Mt. Perrier and St. Prest, belong most probably to this stage of the Glacial Period.

III. SAXONIAN.

To this horizon belong the accumulations of the epoch of maximum glaciation when the Scandinavian *mer de glace* invaded the low grounds of Saxony and the great glaciers of the Alps piled up the moraines of the "outer zone." The stage is well represented, in nearly all the mountain-ranges and elevated plateaux of the continent, by moraines and fluvio-glacial gravels—while heaps and sheets of rock-rubbish and breccia (pseudo-glacial accumulations) point to the action of severe climatic conditions at lower levels. Flood-loams were doubtless also abundantly distributed over the broad valleys and low-lying tracts of extra-glacial regions. But these cannot always be separated from the similar deposits of later glacial stages which must obviously have been deposited over the same tracts. To

the same stage ought to be referred those Pleistocene marine beds of Sicily which are charged with a northern fauna.

The Saxonian thus includes the "lower bowlder-clay" of the British Islands; the "lower diluvium" of Holland, central and southern Germany and central Russia; the ground-moraines and terminal moraines of the "outer zone" (Alpine Lands), and their associated gravels; the older moraines of many mountain tracts in middle and southern Europe; the lower breccias of Gibraltar and much of the "rubble-drift" of other regions.

IV. HELVETIAN (OR ELEPHAS-ANTIQUUS STAGE).

The interglacial deposits of this stage having been first detected in Switzerland suggest the term selected. The Helvetian includes a number of well-known deposits, some being marine, while others are of fresh-water and terrestrial origin. The flora and fauna are indicative of varying climatic conditions. Some of the British beds, for example, have yielded a northern and temperate flora, the mammals including mammoth, woolly rhinoceros and reindeer, while others contain the relics of temperate and southern forms, such as *Elephas antiquus*, *Rhinoceros leptorhinus*, *Hippopotamus*, etc. In like manner, the equivalent beds in middle Europe have yielded northern and temperate floras and faunas—the latter including mammoth, *Elephas antiquus*, Irish deer, horse, etc., while the flora betokens a more genial climate than now obtains but subsequently deteriorating. In central and southern Europe the Helvetian stage is characterized by a temperate flora and fauna—the latter marked by the presence of *Elephas antiquus*, *Hippopotamus*, *Rhinoceros Merckii*, mammoth, etc.

Amongst the more prominent members of the Helvetian group are the interglacial beds of the British area, as in the maritime tracts of the Moray Firth and the Irish Sea, in Lanarkshire, Ayrshire, Edinburghshire, etc.; the Hessle gravels of East Anglia; the beach-deposits of Sussex; the accumulations of Settle Cave, etc. On the Continent, we have certain marine and fresh-water interglacial beds occurring in the Baltic coast-lands;

the interglacial peat, etc., of Holstein, Rixdorf, Kottbus, Moscow, etc.; the lignites of Switzerland and Bavaria; certain beach-accumulations in northern France; the interglacial deposits of Cantal; and the marine terraces cut in the lower breccias of Gibraltar.

To the same horizon I would assign a considerable proportion of the Pleistocene river-deposits of the Thames, the Seine, the Rhine, etc., as well as many of the cave accumulations of western Europe. But to these and other Pleistocene deposits occurring in extra-glacial regions, reference will be made in the sequel.

V. POLANDIAN.

To this stage belong the glacial and fluvio-glacial accumulations of the minor Scandinavian *mer de glace*, and the corresponding deposits in the mountain tracts of central and southern Europe. The extreme limits reached by the minor ice-sheet have been only approximately ascertained, and cannot at present be represented by a hard-and-fast line. As the ice-sheet extended well into Poland, this has suggested the provisional name given to the stage.

The Polandian includes the "upper bowlder-clay" and associated fluvio-glacial deposits of the British Islands; the "upper diluvium" of central Germany, Poland, west-central Russia, etc.; and the ground moraines and terminal moraines of the "inner zone" (Alps) together with their accompanying gravels. Contemporaneous with these are certain valley moraines in other mountain regions; as also rubble-drifts and alluvial accumulations in extra-glacial tracts.

That the Polandian forms a clearly marked stage is shown not only by the circumstance that it is separated from the Saxonian by the intervening Helvetian, but by the notable fact that the path followed by the minor *mer de glace* did not quite coincide with that pursued by the preceding greater ice-sheet. Thus in southern Scotland the track of the later ice-flow crosses that of the former in some places nearly at right angles, and the same is the case upon the Continent. The maximum ice-sheet,

for example, flowed approximately south across Denmark and the southern Baltic area into Holland and north Germany, while the later *mer de glace* had a more westerly trend.

VI. NEUDECKIAN.

The deposits on this horizon are best developed in the coast-lands of the southern Baltic. They are partly of marine and partly of fresh-water origin, and are intercalated between the so-called "lower" and "upper" bowlder-clays of that region. The general aspect of the fauna is temperate—certainly not Arctic. The highest level to which the marine beds have been traced is 114 meters, at Neudeck near Freistadt in west Prussia. Probably many of the older alluvia overlying the Polandian in regions over which the succeeding Mecklenburgian does not extend ought to be assigned to the Neudeckian stage.

VII. MECKLENBURGIAN.

The most notable deposits belonging to this stage are the ground moraines and terminal moraines of the last great Baltic glacier. These reach their southern limits in Mecklenburg. Contemporaneous accumulations are the bowlder-clays and terminal moraines of the large valley-glaciers and district ice-sheets of the British Islands, and the terminal moraines occurring in the great longitudinal valleys of the Alps (= "first post-glacial stage of glaciation" of Penck and others).

To the same stage are assigned the *Yoldia*-beds of Scandinavia, and the 100-foot terrace of Scotland with its Arctic marine fauna. Here also come most of the Arctic plant-beds of the British Islands, as well as those which underlie the older peat bogs of Denmark, south Sweden, etc.

VIII. LOWER FORESTIAN.

This stage embraces the deposits of the great fresh-water lake of the Baltic area (*Ancylus*-beds); the lower buried forests occurring under the peat-bogs of northwest Europe generally; and the *Littorina*-beds of Scandinavia in part. No deposits on this horizon have yet been recognized in the Alpine Lands. The

evidence as to climatic and geographical conditions furnished by the Lower Forestian of northwest Europe is abundant and clear. The wide horizontal and vertical distribution of forest trees betokens not only a more extensive land-surface than the present, but a better climate. The fauna of the *Littorina*-beds also indicates the former existence of more genial conditions in our seas.

IX. LOWER TURBARIAN.

This stage is most characteristically represented by the peat which immediately overlies the lower forest-bed of our turbaries; by the calcareous tufas of Scandinavia, etc.; by the Carse-clays and raised beaches of Scotland, and the Scandinavian *Littorina*-beds in part, and by valley-moraines and corrie-moraines. The invasion by the sea which marked the passing of the Lower Forestian stage was continued into the Lower Turbarian stage. The climate at the same time became more humid and colder—hence the restriction of forest-growth and the increase of snow-fields. In Scotland glaciers here and there came down to the sea and dropped their moraines upon the beach-deposits—the large majority, however, terminated inland, some of these being true valley-glaciers while a larger number were corrie-glaciers. The general distribution of the moraines indicates a snow-line ranging between 2000 and 2600 feet. In Norway the glaciers were correspondingly of more importance—the position of their moraines pointing to a snow-line in South Norway of 2400 feet or thereabout. In the Alpine Lands this stage appears to be represented by the terminal moraines of the so-called "second post-glacial stage."

X. UPPER FORESTIAN.

Overlying the Lower Turbarian of northwest Europe we come again and again upon a second buried forest. The flora and fauna of this stage denote temperate and drier conditions; while the distribution of the forest-bed plainly indicates a formerly wider land-surface, but one not apparently so extensive as that of the Lower Forestian. In Scotland the upper forest-bed distinctly overlies the Carse-clays, etc., of the preceding stage.

XI. UPPER TURBARIAN.

The upper forest-bed is in its turn overlaid by peat — a succession seen in the turbaries over a vast region. Followed from the interior to the coast-lands in Scotland this peat is found passing under the lower raised beaches. The Upper Turbarian was therefore marked by a new advance of the sea. No moraines rest upon these later beaches, and this last epoch of submergence cannot therefore be directly connected with any of the glacial deposits of the interior. It is remarkable, however, that in the highest mountain-groups of Scotland we encounter not only the terminal moraines of the Lower Turbarian, but another and later series, the presence of which implies a snow-line at 3500 feet. In mountains which are under that elevation the lower series of moraines alone puts in an appearance. The inference, therefore, is that the higher-level moraines bear the same relation to the peat-bogs and raised beaches of the Upper Turbarian as the lower-level moraines do to the corresponding accumulations of the Lower Turbarian. This stage must doubtless be represented in Norway by similar moraines at high levels — indeed these are well-known to exist, although they have hitherto been looked upon as simply marking pauses in the retreat of the larger ice-flows of an earlier stage. In the eastern Alps no third "post-glacial stage" of moraines has been recognized, but that is because these mountains have not the requisite elevation. It is in the western Alps that traces of such a stage must be sought for, and I venture to predict that they will yet be recognized.

I should like now to add a few remarks on the methods followed in this attempt to classify and interpret the complex accumulations of the glacial period. In working out the geological structure of a district we all know how helpful it is to discover some well-marked datum-line — some horizon, whose position is fixed, and to which constant reference can be made. Having been assured that interglacial epochs broke up the continuity of the Ice Age, it was obviously important to ascertain

which of the glacial accumulations represented the epoch of maximum glaciation. Here, fortunately, there was no difficulty. For many years geologists have agreed that the lower bowlder-clay of Britain and the corresponding lower diluvial accumulations of the Continent are the products of the epoch of greatest cold. It was not going beyond the limits of cautious induction to infer that the epoch of maximum glaciation in northern Europe must have been contemporaneous with the same epoch in the Alpine Lands and other mountainous districts on the Continent. Nothing, I should think, can be more probable than that the diluvial accumulations of the most extensive Scandinavian *mer de glace*, which advanced into Saxony, must be on the same horizon as the moraines of the outer zone at the foot of the Alpine Lands. We may consider the Saxonian, then, a well-determined horizon. The next step was to ascertain what relation the deposits of that stage bore to other glacial accumulations. In Britain we have long held that our lower bowlder-clay is the product of the first and greatest glacial epoch, for hitherto no older deposit of the kind has been recognized in these islands. But although that be true for Britain it is not so for Scandinavia. In southern Sweden a still older bowlder-clay exists — the groundmoraine of a former great Baltic ice-sheet, which overflowed Scania from southeast to northwest — a direction at right angles to that followed by the *mer de glace* of maximum glaciation. Again, in the Alpine Lands, as Professor Penck and his coadjutors have shown, the epoch of maximum glaciation was similarly preceded by a yet earlier ice age of very considerable severity — the glaciers descending to the low grounds, but not flowing so far as those of the glacial epoch that followed. Further, it has been ascertained that between the groundmoraines of those two successive epochs there intervene fossiliferous deposits — the plants of which denote a much more genial climate than is now experienced in the valleys of the Alps. Moreover, the amount of contemporaneous valley-erosion demonstrates that this interglacial stage was one of prolonged duration. It was only reasonable to infer that such climatic

changes could not have been confined to Scandinavia and the Alps. If interglacial and glacial conditions obtained in those regions it was obvious that our own islands must have been contemporaneously affected. And the evidence of such climatic changes is found, as I think, in the "Weybourn Crag" and "Chillesford Clay" and the overlying "Forest-bed Series" of Norfolk—the former containing a well-marked Arctic marine fauna, while the latter is charged with the relics of a temperate flora, as well as of temperate and southern mammalian forms. To what extent Britain may have been glaciated when the Arctic shell-beds in question were being deposited we can only conjecture—for the later ice-sheet of maximum glaciation made a clean sweep of almost everything. Were it not for the presence of these marine deposits there would be no evidence in Britain to show that the epoch of maximum glaciation was not the earliest of the series. But the existence of a great Baltic glacier, of an Arctic fauna in the North Sea, and of enormous snow-fields and glaciers in the Alps, implies the contemporaneous existence of considerable snow-fields and glaciers in Britain. It may be safely inferred, therefore, that the Saxonian stage, or epoch of maximum glaciation, was preceded by an earlier but less severe glacial epoch (Scanian stage), the genial Norfolkian stage separating the one from the other.

The next succeeding interglacial and glacial horizons have long been recognized. It is generally admitted by European glacialists that the epoch of maximum glaciation was followed by a more or less prolonged interval of genial temperate conditions. In most glaciated regions the Helvetian stage is represented by fossiliferous deposits, which separate the diluvial deposits in which they occur into an upper and a lower series. So well marked is this division in northern Germany, that long before the significance of interglacial deposits dawned upon geologists, an upper and a lower Diluvium had been recognized. The flora and fauna of the Helvetian stage surely indicate conditions not less temperate than the present. Indeed, the plants occurring upon this horizon in middle Europe imply for the

interior of the continent a climate even more genial than that which now obtains. Further, the long duration of the Helvetian epoch is shown by the extensive valley-erosion then accomplished. We may conclude that, at the climax of this particular interglacial stage, the snow-fields and glaciers of Europe were of no more importance than they are in our own day.

If this conclusion be well sustained it is obvious that the ice-sheet of the Polandian stage was separate and independent, and not a mere phase of the greater Saxonian *mer de glace*. The latter had for a long time disappeared before the minor ice-sheet came into existence—and the independence of the latter is still further shown by the fact that its path differed in some important respects from that followed by the earlier ice-flow. In Saxonian times the Baltic basin had little influence upon the general direction of the *mer de glace*, while the course of the succeeding Polandian ice-sheet was obviously to a large extent controlled by that great depression. And similar remarkable differences in the directions followed by the two ice-sheets have been detected in Britain.

From the Scanian to the Polandian the succession is easily read, but from this stage onwards the evidence is rather harder to follow. My own investigations in Britain led me long ago to conclude that climatic oscillations had continued to take place after the formation of our upper bowlder-clay. I found, for example, that subsequent to the retreat of the minor *mer de glace*, underneath which that upper till had accumulated, there supervened an epoch of district ice-sheets and valley-glaciers. The evidence showed clearly enough that the upper till had been partly ploughed out and large terminal moraines piled upon its surface by a still later series of ice-flows. But as no interglacial beds have hitherto been detected between the moraines in question and the underlying bowlder-clay I could not be sure that the epoch of large local glaciers had been separated from that of the Polandian stage by any long interval. It seemed possible that the valley-glaciers were merely the degenerate successors of

the minor *mer de glace*, which after retreating had again advanced, before they finally vanished. Nevertheless it was obvious that this later advance could not have been a slight temporary movement, but must have endured for a considerable time, so as to allow of much glacial erosion and the heaping-up of immense quantities of morainic rubbish, and the deposition of great terraces of fluvio-glacial gravels. These conditions I found characterized all the mountain areas of the British Isles. It is to this epoch, in fact, that the final grinding-out of our more conspicuous lake-basins must be assigned. The relation borne by the district and valley-moraines to the Arctic shell-beds was also significant. These latter overlie our upper bowlder-clay and are of later age than the Kames and Eskers of our lowlands. They show in short that, after the melting of the minor ice-sheet, submergence of the coast-lands ensued, to the extent of at least 100 feet below their present level. They further show that this submergence was contemporaneous with the existence of the district ice-sheets and valley-glaciers—for the morainic gravels of the latter merge with the deposits of the 100-foot terrace; and here and there moraines are associated with the latter. Not only so, but it is obvious that many of the large glaciers descending to the sea along the west coast of the Scottish Highlands, filled the fiords and prevented the formation there of marine deposits. Thus the 100-foot terrace is well developed upon the open sea coast, but suddenly dies off when the fiords are entered. In the basin of Loch Lomond, again, the glacier ploughed out certain shelly clays so that its groundmoraine is charged with the débris of marine organisms. It is noteworthy in this case that the fauna of the shell-beds thus largely demolished does not indicate Arctic conditions—the species are for the most part living British forms, while the fauna of the undisturbed shelly clays of the 100-foot beach is decidedly northern and Arctic.

From the evidences thus baldly stated the following conclusions seemed probable:

1. The retreat of the minor ice-sheet was followed by submergence to 100 or 150 feet, and the sea eventually became ten-

anted by a fauna not essentially differing from that of the present, but the climate may have been somewhat colder.

2. Recrudescence of glacial conditions supervened, and great valley-glaciers descended from the mountains, filling up the fiords, and ploughing out preëxisting marine deposits. The climate at that time was Arctic — as shown by the character of the fauna in the undisturbed shelly-clays.

It seemed to me quite clear, then, that the 100-foot beach and the contemporaneous morainic accumulations indicated a distinct stage of the Glacial Period. But it was not quite so evident that this stage had been separated from that of the minor *mer de glace* by a well marked interglacial epoch. It became necessary, therefore, to consider the glacial succession on the Continent for the purpose of ascertaining what light that could throw on the problem suggested by the British deposits. The geologists of Scandinavia, Finland and north Germany had discovered the existence of certain great terminal moraines, which, as De Geer showed, must have been accumulated by a great Baltic glacier. These moraines were considered generally to mark a pause in the retreat of the minor *mer de glace* — that, namely, of the Polandian stage — and it struck me as not improbable that in them I had the equivalents of the similar accumulations of our islands. Outside of the great moraines there could be no doubt about the occurrence of two bowlder-clays — those, namely, in the Saxonian and Polandian stages. Between the moraines and the shores of the Baltic, however, not only two, but three, or even, in some places, four bowlder-clays are known to occur. As we might have expected, however, the occurrence of two or of one only is most usual. German geologists have classified the drift deposits of the Baltic coast-lands in the same way as those of the Elbe valley — recognizing, as in that region, a lower and an upper Diluvium. In short, they consider the upper bowlder-clay of the Baltic coast-lands to be continuous with the upper bowlder-clay that stretches south from the great moraines of the Baltic ridge into the valley of the Elbe. In this view the lower bowlder-clay of the Baltic coast-lands is on

the same horizon as the bowlder-clay of the Saxonian stage. On comparing the bowlder-clays of the Baltic lands with those that lie outside of the great terminal moraines it seems to me that this correlation cannot be sustained. The lower bowlder-clay of Holland, for example, has been laid down by a *mer de glace* which flowed in a general southerly direction. But this does not hold true of the so-called lower bowlder-clay of Denmark and Schleswig-Holstein. On the contrary, the two bowlder-clays which occur together in the Baltic coast-lands of that region have both been laid down by ice streaming from east to west out of the Baltic basin. The lower of these bowlder-clays extends across the Cimbric peninsula to the North Sea, while the upper is margined by the great terminal moraines.

The former cannot be correlated with the lower bowlder-clay of Holland, etc., but must occupy the horizon of the Polandian. And this conclusion is further sustained by the fact that the so-called lower bowlder-clay of central Holstein is underlaid by an older groundmoraine, from which it is separated by abundant fossiliferous deposits belonging to the Helvetian stage. In short, the lower bowlder-clay of the Baltic coast-lands is on the horizon of the Polandian stage, while the upper bowlder-clay of the same regions is the groundmoraine of the great Baltic glacier, whose utmost limits are marked by the terminal moraines of the Baltic Ridge.

So far, then, the evidence derived from the Continent points in the same direction as that supplied by the equivalent deposits in Britain. But it carries us further, for in the Baltic coast-lines the youngest bowlder-clay (Mecklenburgian) is separated from the underlying bowlder-clay (Polandian) by an abundant series of fresh-water and marine deposits—some of which indicate cold conditions, while others imply a climate not less temperate than the present. Here, then, is the link in the chain of evidence which we miss in Scotland. If a more or less prolonged temperate interval (Neudeckian) separated the Polandian and Mecklenburgian epochs on the Continent, the same must have been the case in Britain.

Having arrived at the conclusion that a distinct glacial epoch is represented in northern and northwestern Europe by the great Baltic glacier and the district ice-sheets and valley-glaciers of Britain, we might well expect to meet with evidence of a contemporaneous advance of the Alpine glaciers. The threefold grouping of terminal moraines and associated fluvio-glacial gravels in the Alpine "Vorland" represents, as we have seen, three successive glacial epochs—the Scanian, the Saxonian and the Polandian. Entering the mountains by the main valleys, no conspicuous terminal moraines are encountered for a long distance. Eventually, however, these make their appearance. They are of very considerable dimensions and indicate a time when all the great longitudinal valleys contained large trunk glaciers—none of which, however, reached within many miles the limits attained by the glaciers of the preceding third glacial epoch. The moraines now referred to constitute Professor Penck's "first post-glacial stage," when the snow-line would seem to have been 3000 feet lower than now. So far as I am aware, there is no evidence of interglacial conditions having supervened before the advent of these early "post-glacial glaciers." The moraines in question might simply indicate a pause in the retreat of the great glaciers of the third glacial epoch. It is inconceivable, however, that the very considerable climatic changes which are evidenced by the Neudeckian and Mecklenburgian stages of northern Europe should not have affected the Alpine Lands. And it is, at all events, probable that the moraines of the "first post-glacial stage" are the equivalents of the great moraines of the Baltic Ridge, and the products, therefore, of a separate and distinct glacial epoch. The absence of any Alpine representatives of the Neudeckian interglacial stage need not surprise us—for, as I shall show presently, the occurrence of such deposits in mountain-valleys must always be exceptional.

The stage which I have termed Lower Forestian is one of the most clearly marked in the whole Pleistocene series. In Britain and Scandinavia its position with reference to underlying and overlying accumulations is precisely similar. An Arctic

flora occupied the low grounds of both countries during the decay and disappearance of the great Baltic glacier and its British equivalents. To that eventually succeeded a vast forest-growth the relics of which underlie our oldest peat-bogs. The lower forest-bed rests, in short, upon the glacial, fluvio-glacial and marine deposits of the Mecklenburgian stage. At the climax of the Lower Forestian a wide land-surface obtained in northwestern Europe, and the Baltic became a fresh-water lake. Eventually, submergence ensued before those genial conditions had passed away—the marine fauna evidencing warmer waters than now lave the coasts of northwestern Europe.

The next stage (Lower Turbarian) is represented typically in Scotland by the peat which overlies the lower forest-bed and by the raised beaches underneath which the Lower Forestian passes out seawards. The same succession occurs in Scandinavia. Thirty years have elapsed since I first pointed out the significance of this old buried forest and its overlying mantle of peat, and the conclusions I then arrived at have since been supported by the independent researches of Professor Blytt and other botanists and geologists abroad. In subsequent years I had succeeded in gathering much additional evidence. I found that the raised beaches and estuarine deposits which overlie the lower buried forest in our maritime districts, when they are followed inland, eventually pass into fluvio-glacial gravels, and I adduced further evidence to show that during the formation of these beaches and the lower peat of the inland tracts small valley-glaciers existed in the Scottish Highlands. The researches of the Geological Survey have since then shown that these glaciers came down to the sea here and there in the west Highlands and dropped their moraines upon the deposits of the fifty-foot beach. These glaciers I described in *Prehistoric Europe* as "post-glacial glaciers"—meaning by that, glaciers which had come into existence after the disappearance of the minor *mer de glace*. The character of the flora of the lower forest-bed and the wide horizontal and vertical range of the trees, and the facies of the fauna of the *Littorina*-beds of the same stage alike

indicate more genial conditions than now obtain in northwest Europe. During the climate of Lower Forestian times it is not at all probable that permanent snow-fields of any kind could have existed in Britain. The glaciers of the succeeding Lower Turbarian epoch were not the attenuated descendants of the great valley-glaciers and district ice-sheets but entirely independent of and unrelated to these.

In southern Norway the great moraines of the Mecklenburgian stage skirt the coast-line. Considerably further inland we encounter another series of large terminal moraines, constituting Dr. Hansen's "epiglacial stage." These moraines I take to be on the same horizon as those of the Lower Turbarian in Scotland. They indicate a snow-line in southern Norway at about 2400 feet, and this corresponds fairly well with the snow-line in Scotland which, during Lower Turbarian times, averaged a height of 2500 feet.

In the Alpine Lands, after leaving the moraines of the "first post-glacial stage," we meet with no more accumulations of the kind until we penetrate far into the lateral valleys, and there another series of conspicuous moraines occurs, forming Penck's "second post-glacial stage." These indicate a depression of the snow-line of about 1600 feet.

The cold, humid conditions of the Lower Turbarian stage were followed by a more genial and drier climate, the evidence of which is abundantly supplied by the upper forest-bed in the peat-bogs of northwest Europe. As this forest-bed with its overlying peat passes out to sea underneath the youngest raised beaches of Britain and the opposite coasts of the Continent, we infer that in Upper Forestian times the land was of wider extent than now. In the Upper Turbarian we in like manner read the evidence of a subsequent relapse to wet and ungenial conditions —the overlying raised beaches indicating further that these conditions were accompanied or followed by partial submergence. To this stage I assign the relatively small moraines which are restricted to the highest mountain-groups in Scotland —the position of these indicating a snow-line at about 3500

feet. Here, however, the evidence lacks the precision of that supplied by the Lower Turbarian. During that stage moraines were deposited upon the fifty-foot beach which overlies the Lower Forestian. But none of the latest high-level moraines approaches the coast-line—we meet with no moraines resting upon the twenty-five-foot beach.

In the mountain valleys of Norway conspicuous moraines occur at higher levels than those which I have correlated with the Lower Turbarian moraines of Scotland, and some of these are probably contemporaneous with the moraines of the Upper Turbarian in Scotland. In the eastern Alps no moraines corresponding to the highest Scottish series are met with, but in the loftier regions of the western Alps they will probably be found when they are looked for.

It is well worthy of note that the glaciers of the Lower and Upper Turbarian stages endured long enough to allow of the erosion of many small valley and corrie-basins. Each glacial epoch indeed was marked by the formation of lake-basins—some excavated in solid rock, others dammed by morainic accumulations. In Scotland the larger valley-lakes date their origin to the epoch of district ice-sheets, etc. (Mecklenburgian stage); a second series of relatively small valley-basins, and innumerable corrie-basins came into existence during the Lower Turbarian stage, while a third set of corrie-basins and a few high-level valley-basins are the beds of the vanished glaciers of Upper Turbarian times.

In every region which has been subjected to glacial action two areas are recognizable—namely a central area of erosion and a peripheral area of accumulation. In the former bare rock predominates and only patchy, interrupted deposits of morainic origin occur—in the latter the products of glacial erosion are accumulated, and the solid rocks are largely concealed. Hence it is in the latter areas that interglacial deposits are most likely to have been preserved. It is further obvious that if one and the same region has experienced a succession of glacial and interglacial conditions, it is rather the accumulations of the later

than those of the earlier epochs that will present themselves. The distribution of the interglacial and glacial deposits of Europe shows this clearly enough. Not a trace of the Scanian bowlder-clay has been recognized in Britain, but it is probably represented by the lowest-lying bowlder-clay of the south Baltic coast-lands. Again but for the Norfolkian beds we should never have known that a genial interglacial epoch followed after the passing of the Scanian stage. The area of glacial erosion was so enormously extended during Saxonian times that preëxisting superficial beds in northern and northwestern Europe were almost completely obliterated. Under the Polandian ice-sheet great erosion likewise took place, but the area affected was not quite so extensive. Hardly a trace of the Scottish lower bowlder-clay (Saxonian) occurs in the mountain regions, it is only in the low grounds that it puts in an appearance—becoming more and more conspicuous as the peripheral areas occupied by the minor *mer de glace* (Polandian) are approached. The same tale is told by the corresponding deposits on the Continent. In a word it is in the peripheral areas of glacial accumulation that the deposits of the immediately preceding interglacial epoch are most abundantly preserved. If this be true of the Helvetian and Polandian, it is true also of the Neudeckian and Mecklenburgian stages. The Neudeckian beds are met with chiefly in the southern coast-lands of the Baltic. So again we cannot expect to meet with plentiful relics of the Lower Forestian stage in the mountain valleys which were subsequently occupied by the local glaciers of the Lower Turbarian. It is only in places where these glaciers descended to the low grounds or entered the sea that they were likely to override interglacial deposits and to cover these with their moraines. And this, as we have seen, is just what happened in Scotland—the fifty-foot raised beach clearly underlies the terminal moraines of Lower Turbarian times.

Similar phenomena confront us in the Alpine Lands. It is in the "Vorländer" and the lower reaches of the great mountain valleys that the successive glacial and interglacial stages are

best represented. Exceptionally, as in the case of the Hötting beds at Innsbruck, interglacial beds have been preserved under the moraine of the great ice-flow of maximum glaciation. But the beds in question had become indurated by infiltration and converted into solid rock before the advent of that great glacier, and consequently were better able to resist erosion.

It is obvious that the accumulations of glacial and interglacial times which occur over so wide a region in northern and northwestern Europe, and are so well represented in the mountain lands further south, must have their representatives in what we may term extra-glacial tracts. I have spoken of the Norfolkian beds of East Anglia as being the only representatives of that stage that we can certainly recognize in northern Europe. But it seems to me most probable that the fossiliferous deposits which underlie the lower bowlder-clay (Saxonian) of middle Germany occupy the Norfolkian horizon. Be that as it may, we cannot doubt that each interglacial stage must have its equivalent amongst the Pleistocene accumulations of non-glaciated regions. This can be demonstrated in the case of the Lower Forestian stage. It has long been known that a great forest-growth characterized northwestern Europe in what is usually termed the "post-glacial epoch," and that partial submergence of the land subsequently ensued. Now the deposits of this so-called "post-glacial stage" are overlaid in Scotland by a series of moraines—the position of which indicates that the snow-line stood at an average elevation of 2500 feet. The flora and fauna of the Lower Forestian, on the other hand, denote a climate even more genial than the present. Hence the Lower Forestian, capped as it is by glacial accumulations, obviously occupies an interglacial position. In a word, the lower peat-bed occurring under the peat-bogs of northwest Europe outside of the regions reached by the glaciers of the Lower Turbarian stage, is the product of an interglacial epoch, to which succeeded an epoch of manifestly colder conditions. On the same principle and for similar reasons I would assign to interglacial horizons all the Pleistocene alluvial and cave deposits of extra-

glacial tracts which have yielded relics of interglacial floras and faunas; while those containing the remains of northern and Arctic forms I look upon as representatives of the several glacial stages.

Thus I would range under the head of Norfolkian not only the "Norwich Forest-bed series" and the equivalent interglacial beds of the Alpine Lands, but the so-called "pre-glacial beds" underlying the Saxonian diluvial formation of middle Germany, etc., together with the *Elephas-meridionalis* beds of France, Italy, etc. The subsequent glacial and interglacial stages must each have representatives in extra-glacial tracts, and I am sanguine enough to believe that the detailed correlation of the former with the latter will some day be accomplished. Already, indeed, progress has been made in this direction. Distinct stages in the Pleistocene alluvia have been recognized not only by means of their organic remains, but by working out their relation to the fluvio-glacial terraces that extend outwards from glaciated regions. In this way it has been proved that no small proportion of the ossiferous and palæolithic river-gravels are on the horizon of the Helvetian interglacial stage. So again with regard to the Löss, recent researches have shown that the areas occupied by this deposit have been tenanted successively by tundra, steppe, and forest-faunas. And, further, as Penck and others have demonstrated, the Löss is not the accumulation of one single epoch, but must be relegated to different stages of the Glacial Period.

Apart altogether from the stratigraphical relations of the Pleistocene alluvia and cave-accumulations to the fluvio-glacial and glacial deposits, it has long been recognized that the organic remains of the former are indicative of climatic oscillations. Did no glacial and interglacial beds exist, we should yet infer from a study of the Pleistocene alluvia and cave-accumulations that great changes of climate must have taken place during their formation. It is clear, in a word, that the Pleistocene deposits of extra-glacial and glaciated regions are merely portions of one and the same geological series—they are of con-

temporaneous origin. Thus, when the former are followed towards regions of glacial accumulation they eventually disappear under bowlder-clay or other diluvial deposits, or else they are found occupying interglacial positions. It was this remarkable distribution that first suggested to me, many years ago, that these ossiferous alluvia could not be of post-glacial age, as was at that time generally supposed.

In raising the number of glacial epochs from two or three to five or six I am aware that I run the risk of exciting prejudice. If it be hard to conceive of a succession of three glacial epochs, it will seem harder still to admit the possibility of double that number having supervened in Pleistocene times. We are so much the slaves of terminology, that had I restricted the term *epoch* to the first three cold stages, and merely described the last three as indicating *episodal* climatic oscillations in post-glacial times, my conclusions would probably have assumed a less disturbing guise. But the evidence was quite antagonistic to such a division. Before I had ascertained that the district ice-sheets, etc., of Britain (Mecklenburgian stage) represented a distinct glacial epoch—so long as I believed them to be merely the attenuated descendants of the minor *mer de glace* (Polandian stage)—it was possible to hold that the Glacial Period closed with the final disappearance of that particular ice-sheet. Thus the deposits of the 100-foot beach were formerly classed by me as "late glacial"—all the overlying accumulations being included in the "post-glacial and recent series." Some thirty years ago I had adduced evidence to show that oscillations of climate had supervened in post-glacial times—a view which was suggested by the occurrence of successive forest-beds in the peat-bogs of northwestern Europe. The researches of subsequent years tended strongly to confirm that view, and in *Prehistoric Europe* (1881) I showed that upon the decay of the great forests which occupy the bottom of the peat-bogs, the land was partially submerged, the climate became colder and more humid, and snow-fields and valley-glaciers reappeared in the Scottish Highlands These I designated "post-glacial glaciers." I had no thought at

that time of including this recrudescence of glaciation as a phase of the Glacial Period proper. I then considered the closing stage of the Ice Age to be represented by the groundmoraine of the minor *mer de glace* and by the moraines of retreat dropped by the great valley-glaciers into which that ice-sheet, as I believed, was finally resolved. The contrast between the *mer de glace* of our upper bowlder-clay, and the terminal moraines of "post-glacial" times was so great that it would have been absurd to include the latter in the Glacial Period proper. The subsequent discovery by Penck of "post-glacial" moraines in the Pyrenees, and the recognition of similar "post-glacial" stages in the Alpine Lands, tended to confirm me in the view that the Glacial Period closed with the disappearance of the vast ice-sheet underneath which our upper bowlder-clay was accumulated. But after I had learned that the district ice-sheets of Britain and the last great Baltic glacier belonged to an independent epoch, separated from the preceding cold epoch by well-marked interglacial conditions of long duration, it became necessary to reconsider the question of classification. The intercalation of the Neudeckian and Mecklenburgian stages at once broke down the climatic barrier, if I may so speak, that seemed at one time to separate glacial from "post-glacial" times. The great contrast between the two no longer exists. What I find is a succession of glacial and interglacial stages, beginning with the Scanian and terminating with the Upper Turbarian. The climax of glacial extension was reached in Saxonian times, after which each cold stage diminished continuously in importance. In like manner the earliest interglacial epoch appears to have been the most genial, each successive epoch approximating more and more closely to existing conditions. In a word, the climates of the later glacial and interglacial phases were less contrasted than those of the earlier stages of the series.

But it may be urged that the earlier climatic stages being so much more pronounced than those of later times, they alone should be considered of epochal importance. Well, much depends upon what we imply by the term epoch. For myself I

use it simply as a vague term signifying a relatively long lapse of time. I do not think we have quite unequivocal evidence to show that any one of these epochs was longer or shorter than another. For aught that we can tell all may have been of equal duration. One is apt to infer that the enormous erosion and accumulation evidenced by the Saxonian implies a much longer time than the corresponding work accomplished, say, in the Lower Turbarian epoch. But we may quite well be mistaken in our inference. A horse will do much more work in an hour than a man can accomplish in the same time. So the vast ice-sheets and glaciers of the Saxonian stage, in the work they were able to perform, must necessarily have surpassed the comparatively insignificant ice-flows of a later date. But it is obvious that the erosion of a rock-basin 600 feet deep and twenty-five miles long need not have occupied more time than was required for the excavation of a basin hardly a mile in length and only a few yards in depth. Again, the Saxonian and Polandian bowlder-clays and fluvio-glacial gravels far surpass in importance those of the Mecklenburgian stage, but he would be a rash geologist who should maintain that the thicker and more extensive accumulations necessarily took the longest time for their formation. I am not aware of any evidence that would compel me to infer that the small local glaciers of the Lower Turbarian did not exist for as long a space of time as their gigantic predecessors of earlier glacial epochs. Once more, if we take into consideration the many complex climatic and geographical changes and the several migrations of flora and fauna which characterized the later phases of the Glacial Period, we shall hesitate before concluding that the Mecklenburgian and succeeding stages are less entitled to be classed as epochs than the more strongly contrasted stages that preceded them. And similar remarks apply to the interglacial stages. I do not know how we are to estimate the relative duration of each particular genial epoch. It can be shown that great valley-erosion took place during the earlier interglacial stages; and the persistence of these epochs is still further indicated by the depths to which surface-weathering

penetrated. If the epigene agents of change worked no more actively then than they did in later interglacial times or than they do in our own day, we should be led to infer that the earlier were of much longer duration than the later stages. But I doubt whether that inference would be justifiable. Such evidence as we have seems to indicate that the climates of the earlier interglacial stages were warmer and more humid than those of later epochs—and this means more active weathering and more energetic fluviatile erosion. If we base our estimate of the duration of the earlier interglacial epochs upon the present rate of erosion and accumulation, then doubtless we shall be led to conclude that these earlier stages were more protracted than the later. But it would seem more reasonable to take the latest interglacial epochs—those, namely, which approached most nearly to existing conditions—and endeavor to measure the duration of these by reference to the present rate of erosion. If we could ascertain approximately the time required for the erosion and accumulation which took place during the Lower or the Upper Forestian stage we should perhaps have a better index to the duration of interglacial epochs generally. In a word, the present rate of epigene action cannot be much less than that of late interglacial times, but it must have been considerably exceeded by that of earlier interglacial stages.

For ready reference I append a tabular statement of the glacial succession in Europe:

EUROPEAN GLACIAL AND INTERGLACIAL STAGES.

XI.	Upper Turbarian	= Sixth Glacial Period.
X.	Upper Forestian	= Fifth Interglacial Period.
IX.	Lower Turbarian	= Fifth Glacial Epoch.
VIII.	Lower Forestian	= Fourth Interglacial Epoch.
VII.	Mecklenburgian	= Fourth Glacial Epoch.
VI.	Neudeckian	= Third Interglacial Epoch.
V.	Polandian	= Third Glacial Epoch.
IV.	Helvetian	= Second Interglacial Epoch.
III.	Saxonian	= Second Glacial Epoch.
II.	Norfolkian	= First Interglacial Epoch.
I.	Scanian	= First Glacial Epoch.

JAMES GEIKIE.

THE CLASSIFICATION OF AMERICAN GLACIAL DEPOSITS.

THE admirable delineation of the glacial deposits of Europe presented by Dr. Geikie in the foregoing paper invites a brief sketch of the American series for purposes of comparison.[1]

Our knowledge of the formations that were deposited during the advancing stages of the glacial period in America is extremely imperfect. Owing to the erosions of the overriding ice and the burial of the residue it is likely always to remain meager. There have been found, however, here and there, remnants of drift which have the appearance of superior age and of separateness from the overlying deposits, and which may therefore represent the accumulations of the earlier stages of the glacial period, but none of these seem as yet entitled to distinct recognition. We would appear, therefore, to have nothing which can be correlated with confidence with the Scanian horizon of Europe, as defined by Dr. Geikie.

A similar observation is to be made respecting the deposits of a stage possibly equivalent to the Norfolkian. In some localities beds of peat and vegetal débris, with accompanying earthy deposits, have been found underneath the lowest drift at the points in question, but I am not aware that there is any specific ground for connecting them immediately with the glacial period. It can simply be said of them that they were accumulated earlier than

[1] In the recent edition of "The Great Ice Age," an outline of the American glacial deposits was given to which the writer begs to refer for some characterizations of the members of the series here omitted or abbreviated. In that sketch the names Kansan, East Iowan and East Wisconsin were given to the three leading till sheets, as at present known, and the Toronto fossil beds were recognized under that name as an important interglacial deposit. Other interglacial deposits were not named, nor the latest members of the glacial series, which would be necessary to carry out a complete parallelism with the elaborate series of Dr. Geikie. Mr. Upham has made the suggestion that the terms East Iowan and East Wisconsin be abbreviated to Iowan and Wisconsin, which is cheerfully accepted, so far as it may be done without danger of misunderstanding.

the earliest known glacial invasion, but whether the accumulation was immediately antecedent (and so contemporaneous with some of the advancing stages of glaciation, or with some of the deglaciation stages that may have interrupted the advance), or whether it was more distantly antecedent, is an altogether open question. The perishable nature of such deposits offers some presumption that they were not very greatly antecedent to the maximum ice invasion, and, to that slight extent, offers a presumption that they were contemporaneous with the earliest stages of the glacial period in the larger application of the term.

The Kansan formation (=*Saxonian ?*).—The earliest formation which has been worked out into sufficient definiteness to merit specific recognition in the United States is an expansive sheet which reaches southward nearly to the junction of the Ohio and the Mississippi and southwesterly beyond the Missouri. The term Kansan has been applied to it because of its great extent in the direction of the arid plains and because it appears in the State of Kansas free from complications with other formations. It consists essentially of a sheet of till with associated assorted drift. Only the assorted material which was essentially contemporaneous with the till is here included. That which overlies it and was not formed at the same time is referred to the succeeding horizon.

There is a striking similarity between the Kansan formation and the Saxonian of Dr. Geikie. They both alike represent the greatest extension of the ice sheet. They are alike in terminating in an attenuated and worn border, in the main. They are neither corrugated by great peripheral moraines, as a rule, nor by longitudinal drumloidal ridges, nor, in general, by great esker systems, or kame aggregations. None of these features are entirely absent, but they have a relatively inconspicuous development. The relations of the two to succeeding formations are essentially identical.

While no correlation across so great an interval as the Atlantic can command the utmost confidence until the cause of glaciation shall have been demonstrated, and shall have been shown

to be such as to operate in like ways on both continents at the same time, it is nevertheless interesting to make such correlation as the formations permit, and it may be profitable if held in due restraint. The parallelism between the Kansan and the Saxonian formations is fairly close and certainly suggestive.

The Aftonian (=*Helvetian?*).—Subsequent to the formation of the Kansan sheet of till, and accompanying assorted deposits, there was a very notable retreat of the ice. Mr. Upham, whose inclination to unify and limit the extent of the glacial period makes his judgment especially valuable on this point, expresses the opinion that the retreat reached an extent of 500 miles.[1] This judgment is based upon the occurrence of interglacial peaty deposits in the basin of Lake Agassiz. If we recognize a subsequent retreat of considerable moment between the Iowan and Wisconsin stages, it will not perhaps be clear that these deposits do not belong to the later interval; but even under this interpretation, the retreat must still probably have exceeded 300 miles. During this stage of retreat there were accumulations of muck and peat reaching a reported depth of twenty-five feet. One of the best exposures of this horizon is found between Afton and Thayer, Iowa, and from the former a euphonious name may be taken. Owing to the scarcity of gravel in the drift territory of southern Iowa, the Chicago, Burlington & Quincy Railway has made very extensive excavations upon three gravel deposits lying between an upper sheet of till reaching a thickness of forty to sixty feet and a lower till of less depth. The gravels appear to be kame-like accumulations, at least they are great lenses lying upon the surface of the lower till. This lower till is believed to belong to the Kansan stage and the upper to the Iowan. On the surface of the gravels there accumulated, at points, a deep mucky soil, in which occur considerable quantities of vegetal débris. This is believed to occupy the same horizon as the numerous peaty deposits described by McGee in eastern Iowa.[2] To this horizon also is referred the peat beds lying between the two outer till

[1] WARREN UPHAM: Am. Naturalist, Vol. XXIX., 1895, March, p. 237.

[2] Eleventh Annual Report U. S. Geological Survey, p. 487.

sheets of southeastern Minnesota, described many years ago by Professor N. H. Winchell.[1] The fauna and flora of this horizon have not yet been adequately worked out, but their general indications are not unlike those of the Helvetian stage of Europe, as defined by Dr. Geikie. A tentative correlation of the two may therefore be made.

The Iowan formation (=*Polandian?*).—This embraces an extensive sheet of till lying upon the preceding interglacial deposits and having its best known expression in eastern Iowa, where it has been most carefully worked out by McGee. It is known to have considerable extension in adjoining states, but its full distribution is not yet ascertained. It is intimately associated with the most important of the loess deposits. In some places it appears to graduate at its edge into loess which spreads far away from its border. In other places, it seems to pass up by graduation into a loess mantle. To avoid misunderstanding it should be remarked that minor deposits of loess are associated with other sheets of drift, and loess is not necessarily characteristic of any horizon. The close association of the greatest loess deposits with the Iowan formation is, however, significant of the conditions under which it was formed.

The Iowan formation stands in a relation to the American series similar to that of the Polandian to the European series. It has, furthermore, similar characteristics in constitution and surface expression. I believe I am correct in saying that the chief loess deposits of south Germany and Russia are associated with the Polandian formation in much the same way that the chief loess of the Mississippi basin is associated with the Iowan deposits. In a tentative correlation, therefore, the Iowan and the Polandian formations may plausibly be regarded as equivalents.

The Toronto formation (=*Neudeckian?*).—Through the recent investigations of Coleman[2] and others, and the earlier studies of

[1] N. H. WINCHELL: Proc. A. A. A. S., Vol. XXIV., 1875, Pt. II., pp. 43–56; Geol. Minn., Final Rep., Vol. I., 1884, pp. 313, 363, 390.

[2] A. P. COLEMAN: Interglacial Fossils from the Don Valley, Toronto. Amer. Geologist., Vol. XIII., February, 1894, pp. 85–95.

Hinde,[1] it has been shown that there is a very important series of fossiliferous beds in the vicinity of Toronto, interstratified between till sheets. There are two series of fine laminated shales and sandstones separated by a sheet of till, with till overlying the whole, and presumably also underlying the whole. In the lower stratified series, whose thickness Dr. Hinde gives as 140 feet, the silts and sands contain organic remains from bottom to top. These embrace a considerable variety of forms, the most notable of which are the remains of lepidopterous insects, all of which have been pronounced by Scudder to be extinct. These beds are exposed on the face of Scarborough Heights a few miles east of Toronto. Along the river Don, in the immediate suburbs, Professor Coleman has found a remarkable group of molluscan forms and of plants in laminated clays and sands that were at first supposed to be equivalent to the fossiliferous series of Scarborough Heights. But Professor Coleman informs me that he has reasons for doubting the correctness of this correlation, and thinks it not impossible that the beds on the Don may correspond to the upper clays and shales in the Scarborough section. If this should prove true (and this statement should not be construed as in any way committing Professor Coleman) we shall have here two fossiliferous series requiring correlation. The series on the Don contain molluscan forms, chiefly unios and their relatives, which belong to the Mississippian, rather than to the Atlantic, drainage area. They also contain plants that indicate a more genial environment than that of Toronto at present. From the fact that the molluscan forms appear to have passed over the divide between the Mississippi and the St. Lawrence basin after the retreat of the earlier ice, and to have been subsequently forced out of the basin, presumably by the return of the ice, which formed the overlying till sheet, it has seemed possible, if not probable, that the beds upon the Don belong stratigraphically between the Iowan and the overlying Wisconsin beds. It will be observed that the grounds

[1] GEORGE JENNINGS HINDE: The Glacial and Interglacial Strata of Scarborough Heights and other localities near Toronto, Ontario. Can. Jour., April, 1877.

for this correlation are not very strong, and investigation may show them to be erroneous. It is not likely, however, that the beds upon the Don can be referred to any earlier period. They may be later. Should the beetle-bearing beds at the base of Scarborough Heights prove to be distinct from the molluscan beds on the Don, the former may perhaps be found equivalent to the Aftonian beds previously described. Whether the beds on the Don belong to the horizon suggested or not, it is certain that vegetal beds were formed in the interval of the retreat between the formation of the Iowa till and the formation of the Wisconsin till, and some of these less well developed and less known deposits must be looked to as a type of this interglacial horizon, if the Toronto beds prove unavailable.

If the fossiliferous clays and shales on the Don belong to the interval between the Iowan and Wisconsin formations, they may be tentatively correlated with the Neudeckian of Geikie.

The Wisconsin formation (= *Mecklenburgian*?).—Overlying the interglacial beds above the Iowan deposit, comes the most massive of the American till sheets, occupying the larger part of the territory of the northern states and very large sections of Canada. This is distinguished by a series of gigantic terminal moraines, stretching across the country in an undulatory fashion already well known to students of the subject. There are at least two divisions of the moraine-bordered tills, with a somewhat notable interval between the two, during which there was considerable rearrangement of the frontage of the ice. As a result of this, some of the later moraines run at large angles across the earlier ones, riding over them in a quite disregardful fashion.

In like manner there occurs upon the northern plains of Germany a series of similar gigantic moraines associated with thick till sheets. There are also pronounced but less massive moraines in southern Scandinavia and Finland. The two series are interpreted as representing a single stage by Dr. Geikie, but to one at a distance, and without personal familiarity with deposits, the suggestion that they represent two episodes having some such relation to each other as the two subdivisions of the

Wisconsin formation arises, and may be mentioned for what it is worth, which is probably very little. The chief characteristics of the European morainic series are strikingly similar to those of the American, as long since pointed out by Salisbury.[1] In addition, therefore, to the similarity of position in the European series which the Mecklenburgian series bears to that of the Wisconsin formation in the American series, there is a striking correspondence in the individual characteristics of the two. Beyond any question these individual characteristics were due to some common condition or combination of agencies. If the fundamental cause of glaciation was such as to involve intercontinental contemporaneity of action, the correlation of the two has much in its support.

Later deposits.— Investigation in America has gone far enough to make it certain that subsequent to the deposit of the Wisconsin formation, there was a somewhat complex series of events before the Ice Age entirely passed away. It has not, however, gone far enough to make it clear precisely what the stages were, and it is perhaps premature to attempt to designate the specific formations which resulted. A series of beach lines along the lower lakes has been specifically connected with moraines by Leverett and others, indicating a coincidence of lake action and ice action. On the north side of the lakes it is known that there are several very considerable terminal moraines indicating at least halts, and possibly advances, of the ice subsequent to its retreat from the territory of the United States. It is every way probable that some of these will deserve a special taxonomic place when sufficiently traced out. If the fossiliferous beds of Toronto are later than the Wisconsin formation, they and the overlying till certainly merit special recognition. There is therefore abundant room for the belief that stages of action equivalent to the Turbarian and Forestian of Dr. Geikie may be found.

In carrying out this parallel, it has not been the design of the

[1] R. D. SALISBURY: Terminal Moraines in Northern Germany. Am. Jour. Sci., 3d series, Vol. 35, 1888, pp. 401–407.

writer to indicate a judgment respecting the specific value of the several formations, either in terms of taxonomy or chronology. It has been thought, however, that it would promote a mutual understanding of the formations of Europe and America if some approximate equivalence could be shown between the two unquestionably complex series. It will perhaps promote the differentiation of the two series to institute mutual comparisons, and it may facilitate a final judgment of the value of these subdivisions if we are able to compare, formation by formation, the distant series with that which falls within our own field of investigation.

T. C. CHAMBERLIN.

THE VARIATIONS OF GLACIERS.

THE great interest which the physical study of living glaciers has to the geologist is the light it may throw on causes producing, and conditions prevailing during, the Ice Age. One of the habits of living glaciers bearing most directly on the Ice Age is the variation continually occurring in their length, thickness and velocity of motion. All students of glaciers have collected reports and made observations themselves on the advance and retreat of the ends of particular glaciers, but it is only within about twenty years that anything like systematic work has been done in getting together records which enable us, in some cases, to exhibit roughly the variations in the extent of certain glaciers for three hundred years, during which period there has been quite a number of advances and retreats; observations since the fifties give us a fair record of the movements of some Swiss glaciers.

What are the causes of these variations? The answer of course is that they are meteorological, for it is quite evident that the extent of a given glacier depends on the snow-fall and the rate of melting; the ice continues to flow down its valley until it is all melted away. Anything that increases its velocity will make it flow further, and anything that increases its rate of melting will cut it off shorter. But which of these factors has been most important in determining the changes which have actually occurred? M. Forel has argued ably[1] that it is the change in velocity. He has shown that glaciers have varied very much in extent when there has been no great change in the rate of melting; that this has been due to a change in the velocity, which in its turn depended on a change in snow-fall. If this proves to be universally the case we have the following interesting application to make to the ice of the Ice Age: If the

[1] Bibliotheque Universelle de Geneve, VI., pp. 5–49, 448–460.

floods which occurred at the time when the ice-sheet was at its maximum (*i. e.*, when the melting-area was greatest), were stronger than those which occurred later, we may infer that the retreat of the ice was due rather to a diminution of the snow-fall than to an increased rate of melting, brought about by a warmer climate; whereas, if the stronger floods occurred after the ice had retreated some distance (*i. e.*, when its area was smaller), we may infer the opposite.

How soon does a glacier respond to climatic influences? This is a question which cannot be answered directly; usually we find some glaciers advancing and others retreating at the same time; for instance, a little before the middle of this century the Alpine glaciers were apparently all advancing; one after another ceased to advance and began to shorten, the number joining the retreating forces being greatest between 1850 and 1860; but it was not until 1870 that all were losing ground; for five years thereafter no glacier in the Alps was known to be advancing; in 1875, the glacier des Bossons, on Mt. Blanc, led the beginning of a new advance; since then others have joined it, until now some fifty or sixty are advancing. Peculiarities show themselves in the changes; glaciers in the same mountain group, and even glaciers so closely related as the Findelen and Gorner, near Zermatt, whose *névé* regions adjoin, are sometimes moving in opposite phases at the same time. In general there seems to be a readier response on the part of the smaller glaciers; and the steeper ones also seem to start earlier than the others; but as far as I know variations have not been analyzed according to the size, slope, height, exposure of the glaciers, etc.; in fact, it would be extremely difficult to analyze them properly without the guidance of a mathematical theory, which would enable us, when given the dimensions of a glacier, to calculate the velocity in its different parts. Material, however, is being collected which will form a basis for such a theory, in the general records of the movements of glaciers, and more particularly in the accurate observations which are annually made on the Rhone glacier under the auspices of the Swiss Alpine Club, and on some other glaciers.

M. Forel has collected and discussed the records of variations of glaciers in a series of most interesting reports to the Swiss Alpine Club.[1] He finds that glaciers go through periodic changes of from thirty-five to fifty years' duration.[2] Beginning with a glacier at its minimum the changes occur in the following order: First comes an increased velocity due to increased snow-fall, and the glacier advances rather rapidly; later the velocity diminishes, the glacier reaches its maximum, and then begins to retreat. During this whole period the rate of melting may not have changed at all markedly. The advance is rapid, taking about a third as long as the retreat, which is merely a time of melting, during a diminished flow, until a new advance, produced by increased snow-fall, begins again. The average for quite a number of glaciers observed during this century gives a complete period of thirty-eight years or more. But the subject is much complicated by the fact that different glaciers begin and end their advance at widely different times; so different indeed, that we can frequently in a given year find different glaciers representing all phases of advance and retreat. This makes the task of comparing variations of climate with variations of glaciers very difficult, for one does not know what to consider the time of maximum or minimum advance.

Some progress has however been made; Professor Brückner[3] starting with the fact that glaciers have periodic changes, made an exhaustive study of the variations in the heights of lakes, of interior seas; of the inundations of rivers, and the duration of their winter freezing; of agricultural matters, such as the times of vintage, etc., and found a similar period in them all. He then took up meteorological observations proper and found the same thing. His researches reach back to 1700. He was able

[1] Jahrbuch des Schw. Alp. Club, from 1881 to date. I am indebted to Professor Forel and Professor Richter (cited below) for almost all the material of this paper.

[2] American glaciers are in general retreating, but observations have not been frequent enough to show a periodicity in their movements.

[3] Klima-Schwankungen seit 1700. Geog. Abhand. von Dr. Penck, 1890, IV. (cited by Professor Forel).

to state that since then, and presumably before, the climate has oscillated about its mean in a period of thirty-five years. Professor Richter[1] by a careful study of the historical records of Alpine glaciers, has confirmed this, and has carried it back another hundred years. He has shown that the average period of the variations of glaciers for the last three hundred years has been the same as Brückner's period. He has also shown that during the present century the larger number of glaciers have begun to advance very soon after the beginning of a cold period of increased precipitation, though some of the larger ones have started only twenty or even thirty years later. We wish now to know the relation connecting the time of increased precipitation with the time of advance of glaciers, as a function of their size, slope, etc.

Two theories have been advanced to explain the *modus operandi* of glacial variations. Professor Richter[2] thinks that there must first be an accumulation of snow in the *névé* regions, which at last produces a great enough pressure to overcome the resistance, due to the friction against its bed, of the glacier's tongue; which is then pushed forward with a greater velocity, resulting in an advance of the glacier; this continues until the drain on the *névé* regions, on account of more rapid flow, exhausts the accumulation of snow; after this the motion almost entirely ceases, and the glacier melts back until another advance begins. Professor Forel[3] calls this the "theory of intermittent flow," and points out that according to it variations in the size of glaciers would occur entirely independently of meteorological changes. He had, in 1881, offered a "theory of continuous flow."[4] According to this theory the glacier responds immediately to increased snow-fall, but only in its upper part is there an immediate increase in velocity; this pressing forward of the ice

[1] Geschichte der Schwankungen der Alpengletscher. Zeits. des deut. u. Oest. A–V., 1891. This is a most important paper.

[2] Der Obersulzbach Gletscher, 1880–82. Zeits. des deut. u. Oest. A–V., 1883.

[3] Jahrbuch des Schw. Alp. Club, 1887–88.

[4] Bibliot. Univ. de Geneve, 1881.

from above results in a progressive thickening of the glacier from above downward. Though the increase in the thickness and velocity may have begun in the upper regions, the end may still be melting back; when, however, this increase in thickness reaches the lower end the advance will begin, for there will be a greater quantity of ice and it will have a greater velocity; it will therefore have to travel further before being melted away. After a while, the snow-fall becoming less, the glacier will gradually decrease in thickness, and consequently in velocity, until the rate of melting exceeds the rate of flow, when the retreat will begin. Comparatively small changes in snow-fall result in marked movements of the glacier's end; for not only is the thickness of the ice at the end changed, but the velocity is also, and these

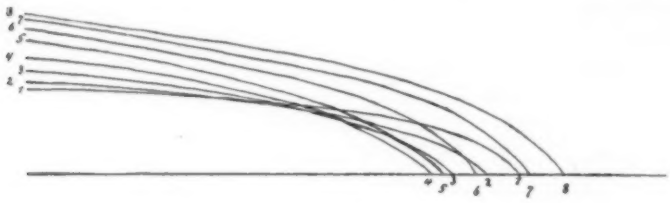


FIG. 1.

two factors so interact that an increase of one produces an increase of the other, and the reverse. This can be made clearer by a diagram.

In Fig. 1, let line 1 represent the surface of the glacier when the *névé* fields are lowest; suppose now the snow-fall increases; the *névé* fields get thicker, but the end is not affected, and it continues to melt back; the lines 2, 3, etc., represent the surface at successively later times. After a while the thickening and consequent increase in velocity of the lower end causes it to advance.

Similarly the continued advance after the snow-fall has begun to diminish, and the later retreat, may be illustrated by Fig. 2.

The question of glacial erosion is a very important one; the

geological evidence has not led geologists to a uniform opinion. We know little about the velocity below the surface of the glaciers; can we find out how rapidly glaciers are sliding over their beds? This is certainly very difficult to do; in fact the only place where observations can be made is near the end of the ice or at the sides where the movement is slow. During the last thirty or forty years, a period of retreat, the movement has been slower than it will be during the advance now beginning; observations made during the retreat would certainly lead to an underrating of the effect of a glacier on its bed; but during the more rapid movement of the advance we shall form a better estimate of it. A mathematical theory might enable us to infer

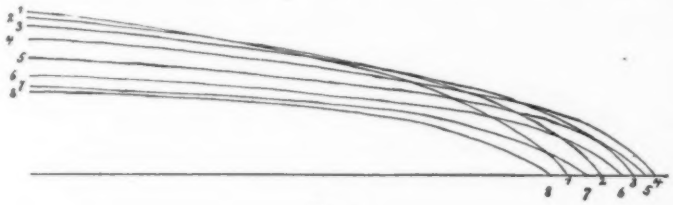


FIG. 2.

the velocity at the bottom from that at the surface; this would certainly be an immense gain in our knowledge of glaciers and ice-sheets. It is for this reason that experiments on the physical properties of ice, and observations on the rate of flow, rate of melting, and comparisons of the variations of glaciers with climatic variations, etc., are of so much importance to the glacial geologist.

The study and observations of the variations of glaciers is being pushed with great zeal by the various Alpine clubs, and the results published in their journals, where they are apt to escape the notice of American geologists. Last summer the International Congress of Geologists at Zurich appointed a committee to encourage, and to collect, observations on glaciers all over the world, with the special object in view of discovering a relation between the variations of glaciers and of meteorological

phenomena.[1] It is with the hope of enlisting the coöperation of American geologists, and others who may be willing to help, that this paper has been written.

There are a number of small glaciers in the Sierra Nevada mountains, larger ones on the old volcanoes of the Cascade Range and in British Columbia, and immense ones in Alaska. Opportunities for making observations on many of these glaciers will frequently arise, even to travelers, who, if willing, can contribute to the problem of the variations of glaciers.

There are two glaciers in North America that are so frequently visited that we should secure a very complete set of records of them; they are the Illecellewaet in the Selkirk Mountains and the Muir in Alaska. I add a short list of the observations that should be made, and the methods; many are simple, and easily made by travelers.

OBSERVATION OF GLACIERS.[2]

It is desired to obtain a general description of little known glaciers; to determine at the time a glacier is visited whether it is advancing, retreating or stationary; to determine the year of maximum advance or retreat; to collect observations of travelers which may throw light on the extension of a glacier at an earlier

[1] This committee representing various countries is as follows:

Austria: Professor Ed. Richter, Graz.
Germany: Professor S. Finsterwalder, Munich.
United States of America: Dr. Harry Fielding Reid, Baltimore.
Denmark: Dr. R. I. V. Steenstrup, Copenhagen.
France: Prince Roland Bonaparte, Paris.
Great Britain and Colonies: Captain Marshall Hall, Dorset.
Norway: Dr. A. Ojen, Christiania.
Russia: Professor Ivan Mouchketow, St. Petersburg.
Sweden: Dr. F. U. Svenonius, Stockholm.
Switzerland: Professor F. A. Forel, Morges; Dr. Leon Du Pasquier, Neuchatel.
A representative of Italy has not yet been appointed.

[2] In making out this list of observations and methods, I have had the advantage of consulting the papers of PROFESSOR FOREL in the Jahrb. des Schw. A. C., 1882–83, 1883–84, 1890–91; the instructions of PROFESSORS KILIAN and COLLET in the Annuaire de la Soc. des Tour. du Dauphine, for 1891, and the memorandum of the Alpine Club, cited below.

date; to record the extent and thickness of the glacier as often as possible; to determine the velocity of flow of the ice; to determine the rate of melting of the ice.

General description.—Name. Latitude, longitude and altitude of end. General direction of flow.

General description of glacier (Is it long or broad? Is it in a narrow valley, or on a plateau? Is it simple or made up of several tributaries? Is it smooth or much crevassed? Are there any ice-falls? Are there moraines on the ice? Altitude of *névé* line; size of *névé* fields and of tongue; a sketch map of an unsurveyed glacier is useful).

Slope of glacier.—(1) Slope of surface in different parts of the glacier; (2) estimate of slope of glacier's bed, where possible.

Old moraines.—Describe their forms, condition and distance from the glacier, if terminal, and their height above the ice, if lateral.

Lakes.—Are they true rock-basins or dammed lakes? For rock-basins determine the form of the bed by soundings, if possible.

Recent changes.—(*a*) Question anyone who may be able to give information whether the glacier has recently been larger or smaller than at present, and when it began to advance or retreat.

(*b*) Obtain photographs of the glaciers with date when taken. "The earlier recent movements of glaciers may be noted by the following signs:

"When the ice is advancing, the glaciers generally have a more convex outline, the ice-falls are more broken into towers and spires, and piles of fresh rubbish are found shot over the grass of the lower moraines. Moraines which have been comparatively recently deposited by advancing ice are disturbed, show cracks, and are obviously being pushed forward or aside by the glacier.

"When the ice is in retreat, the marks of its further recent extension are seen fringing the glacier both at the end and sides in their lower portions; the glacier fails to fill its former bed, and bare stony tracts, often interspersed with pools, or lake-

lets, lie between the end of the glacier and the mounds of recent terminal moraines."[1]

Future changes.—For this purpose all records of the extent and thickness of the ice at date of observation are useful.

The position of the end may be recorded as follows:

(*a*) Measure distance of one or more points of the glacier's end from cairns or prominent rocks, which should be marked by paint or chisel. Or, take magnetic bearings of a tangent to the end of the glacier from a station on the valley's side; this tangent should be about at right angles to the direction of the valley.

(*b*) Photographically.—(1) All photographs of the end of the glacier are useful; particularly if the magnetic bearings of the camera, and the approximate distance from the glacier are given. (2) Select two stations, one on each side of the valley, commanding a view of the glacier's end. Photograph the end from these two stations; two photographs from each station may be required to show all the end. Mark the stations, describe them carefully and leave an account at the ranch or hotel from which the glacier is usually visited so that they can easily be found by later observers, who should take photographs from these points in preference to all others. This will be the beginning of a systematic record of the glacier. From these photographs it will be possible to make a map of the glacier's end if we know: the distance between the stations; the angle at each station between the other and some point in each photograph and the focal length of the lens, or the angles at each station between the other and two points in each photograph, not less than half the length of the plate apart; the bearings of these two points will enable us to determine both the direction in which the camera was pointed and the focal length of the lens.

An observer, provided with a small theodolite (or even a prismatic compass) should measure from each of the stations the angle between the other and all prominent peaks or other points likely to appear in the photographs, and should determine the distance between the stations. This need only be

[1] Memorandum on Glacier Observations, issued by the Alpine Club, June, 1893.

done once, after which all earlier and future photographs taken from these stations can be used to mark accurately on the map the glacier's end at the date they were taken. If vertical angles also are measured, and the difference in altitude of the stations determined, contour lines can be added to the map. This method yields the greatest amount of information for the least amount of trouble.

The stations should be selected so as to be as easily accessible and recognizable as possible; the distance between the glacier's end and the line joining them should be between one-seventh and twice their distance apart; nearer the former if the glacier is retreating, nearer the latter if it is advancing.

In taking the photograph have the camera as level as possible, with the plate vertical; do not use the swing back, and do not alter the focus in taking two or more pictures from the same station. Hand cameras should rest on some support; a rock answers well. The longer the focal length of the lens, the better; negatives or positives on glass yield more accurate results than prints, as the paper may become distorted in the manipulation.

Variations of thickness.—(*a*) Select a station on the side of the glacier's valley. Mark it. Select a direction about at right angles to the glacier and record it by compass bearing or by the angle it makes with some easily recognizable point. Determine by aneroid barometer the difference in level between the station and the following points on this line: (1) the sides of the glacier; (2) the highest point of the glacier; (3) any other points feasible. If possible record the difference in level between station and the end of the glacier or some base station.

(*b*) Observe by aneroid or measure the vertical distance between some easily recognizable point in the *névé* region, such as a projecting rock, and the glacier's surface at its side. If possible note difference of level between this station and some base station.

Velocity of flow.—Persons provided with instruments can readily determine the velocity of flow by sighting on a line of stakes or on some prominent bowlders at intervals of a few days.

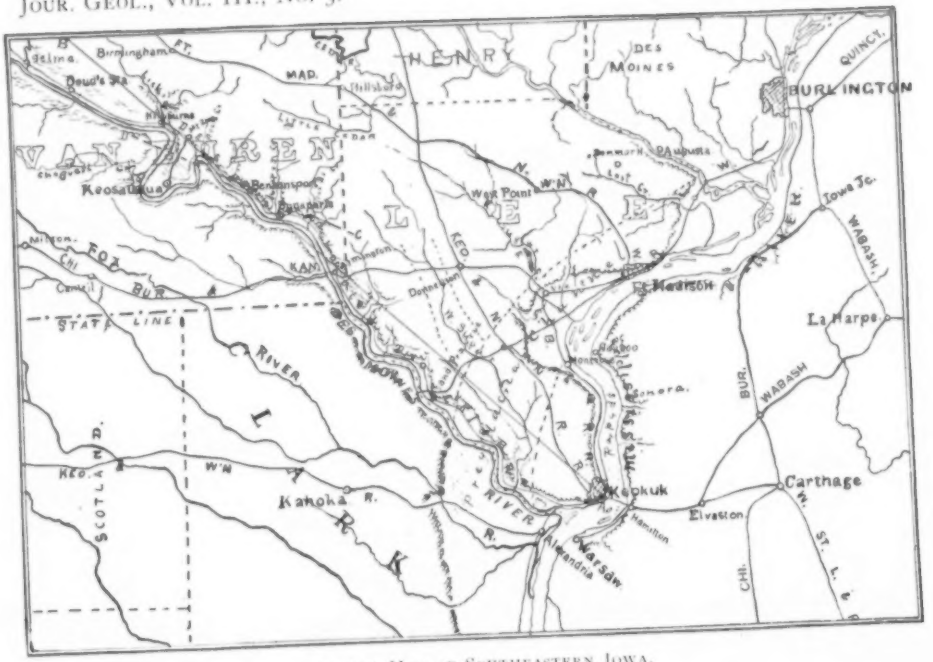
Another method, which yields average velocities, is to determine the position on the ice of some prominent bowlder which is marked, so that it can be recognized after one or more years, and the distance it has moved measured. A very good way is to lay out a line of sheet-iron plates, say, three inches square, on which is painted the date when, and the position where, they are placed. These will sink slightly into the ice, will not be blown away by the wind, and will not roll or slip, as bowlders may. They can be recovered and the distance moved over determined by a future observer. Stones are used in this way for the observations on the Rhone glacier.

Rate of melting.—At the lower end of glaciers, when the ice is somewhat disintegrated and will not in general hold water, the melting can be measured by boring an auger hole in the ice and putting a stick in it; the apparent rise of the stick out of the ice will be the measure of the melting. If the ice is compact enough to hold water, this method may yield inaccurate results; it is better then to bore two holes starting from the same point on the surface of the ice and making an angle with each other of 45° to 60°, put a stick in each hole and where they cross bind them firmly together with wire. The ice will melt around the sticks, but each will prevent the other from sinking into its deepened hole. The wire may be used as an index, and its increasing height above the ice will measure the melting.

All photographs and observations sent me[1] will be carefully filed away and preserved as the record of the history of the glacier in question; they will be considered as the property of the Geological Society of America. A poor photograph is much better than none. Prints should be mounted on linen or unmounted. On each should be marked the glacier depicted the date, the station from which the picture was taken, the direction in which the camera was pointed and whether or not the lens used was rectilinear (or give the name of the lens). If its focal length is known, it should also be given.

HARRY FIELDING REID.

[1] Address Johns Hopkins University, Baltimore, Md.



SKETCH MAP OF SOUTHEASTERN IOWA.

STRATIGRAPHY OF THE SAINT LOUIS AND WARSAW FORMATIONS IN SOUTHEASTERN IOWA.[1]

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    The Warsaw arenaceous beds.
    The brown magnesian limestone.
    The compact gray limestones.
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Unconformities.
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INTRODUCTION.

THE stratigraphic relations of the Saint Louis and Warsaw groups in southeastern Iowa have not hitherto been satisfactorily established. The beds succeeding the geodiferous shales of the Keokuk group, first erected into an independent group—the Warsaw—by Hall in 1858, have been included in the Saint Louis group by some writers, while others have referred them to the Keokuk. From a careful survey of the literature it is evident that much of the confusion attending our knowledge of these rocks has arisen from discordant conclusions derived from investigations within the area covered by this paper. As these differences appear to have arisen chiefly from the variable character of the Saint Louis limestone, special attention was given to

[1] Published with the permission of the state geologist of Iowa.

the study of this formation by the author, in the field work of 1893, under the auspices of the Iowa Geological Survey.

EARLIER DESCRIPTIONS.

Owen, 1852.—The first account we have of the geology of this region is that of Owen in 1852.[1] While detailed work was not attempted, his descriptions give evidence of close and accurate observation. He divided the Lower Carboniferous into an upper and a lower series, and named the various subdivisions from lithological or faunal characteristics. No attempt was made to correlate with rocks in other regions of the United States, but in accordance with the prevailing usage of that time he essayed to establish the equivalency of the divisions of the upper series with the members of the Carboniferous section of Yorkshire.

OWEN'S SECTION OF THE LOWER CARBONIFEROUS.

Upper Series.

f. Upper concretionary limestone.
e. Gritstones.
d. Lower concretionary limestone.
c. Gritstones.
b. Magnesian limestones and shales.
a. Geodiferous beds.

Lower Series.

f. Archimedes limestones.
e. Shell beds.
d. Keokuk cherty limestones.
c. Encrinital group of Hannibal.
b. Encrinital group of Burlington.
a. Argillo-calcareous group of Evans Falls.

The gritstones (*e*) of the upper series are said to be marked by the presence of lepidodendron, calamites, and other Carboniferous plants. The sandstones here referred to are, doubtless, the Keosauqua sandstones. Careful search, however, has

[1] OWEN, D.D., Geological Survey, Wis., Ia. and Minn. U. S. Govt., 1852, p. 92.

failed to reveal any plant remains in this deposit, and it is evident that Dr. Owen confounded this sandstone with the basal sandstone of the Coal Measures which is often found occupying depressions eroded in the limestones. Moreover, the study of the region shows that while the succession represented by *c*, *d*, *e*, *f* of the upper series is in a general way correct for particular localities, the members are rather local in their development, and grade more or less into each other. They cannot, therefore, be assigned a position equivalent to the remaining and more general members of the section. The brecciated limestone so often referred to by later writers is included under the lower concretionary limestone (*d*), though very little is said of it.

Hall, 1858.—In the report issued in 1858,[1] the formations are treated in greater detail and a fuller classification is adopted. The geodiferous beds are included in the Keokuk group, while Owen's divisions, *b* and *c* of the upper series, are erected into the Warsaw group, so named from the town on the east bank of the Mississippi, opposite the mouth of the Des Moines River. The remaining members of the series are referred to the Saint Louis group as established by Shumard of the Missouri survey.

Worthen.—In the report made by Worthen on the geology of the Des Moines Valley, the Keosauqua sandstone is evidently identified with the basal sandstone of the Coal Measures. In the report on the geology of Lee county referring to the brecciated limestone he says: "The changes in the lithological characters of this bed, which forms one of its most striking peculiarities, probably led Dr. Owen into the erroneous supposition that there were two distinct beds of concretionary limestone which he has represented in his general section with a bed of sandstone between." Since Dr. Owen's section can be verified locally, as will appear in the sequel, the error is clearly on the other side. Moreover, the magnesian limestones at the base of the Warsaw[2] group are identified with those occurring on the Des Moines containing *Lithostrotion canadense*, and hence unquestionably belonging to the Saint Louis limestone, a conclusion directly contrary

[1] Geology of Iowa.

[2] Vol. II., Part. I., p. 193.

to the recognition of the Warsaw as a distinct group. In 1866, Geology of Illinois, Vol. I., these formations are held to be related to the Saint Louis and are all included under that group.

White, 1870.—In this report[1] the description of these rocks is still more contradictory. The beds included under the Warsaw group were all referred to the Saint Louis apparently under the erroneous assumption, previously made by Worthen, that the magnesian limestones at the base of the Warsaw are the equivalents of the Lithostrotion beds along the Des Moines. In referring to the character of the Warsaw beds as seen at the typical locality this author says: "The bluish argillaceous shales which so prominently characterize the exposures of this formation at Warsaw are scarcely recognizable in Iowa."[2] This statement, however, is at variance with Hall's observations, as also our own, as shown by sections given in this paper. Moreover, the sandstone or arenaceous limestone representing the upper member of the original Warsaw is correlated with the Keosauqua sandstone, whereas the former is underneath the brecciated limestone, while the latter is above.

In 1890 the writer[3] called attention to the brecciated character for the purpose of suggesting a possible explanation of its origin.

Keyes, 1893.—In Vol. I. of the Iowa Geological Survey[4] the Warsaw beds are recognized as being closely allied to the Keokuk group faunally, stratigraphically and to a less marked degree lithologically. It is not regarded as of sufficient importance to warrant a separation and is, therefore, included in the Keokuk group, while the discontinuance of the name Warsaw as a title equal in rank to Saint Louis, etc., as advocated by White is sustained. As the removal of the Warsaw beds carried with them their supposed equivalents, the magnesian limestones along the Des Moines, the brecciated limestone is described as constituting the basal member of the group in Iowa.

[1] Geology of Iowa, Vol. I.

[2] Geology of Iowa, Vol. I., p. 218.

[3] American Naturalist, April, 1891.

[4] KEYES, C. R.: Geology of Iowa, 1892, Vol. I. p. 70.

FIG. 1.—Section line A-B from Keokuk to northwestern corner of Van Buren county. (See map.)

GENERAL DESCRIPTION OF THE REGION.

The area included in this investigation comprises the two counties of Lee and Van Buren. The former lies on the north side of the Des Moines River at its confluence with the Mississippi, while the latter joins Lee on the west and is traversed by the Des Moines River diagonally from northwest to southeast. This river and most of its tributaries, as well as those of the Mississippi, have penetrated the drift and cut deep channels into the underlying rock, thus offering favorable opportunities for the study of these formations.

The general relief of the region is that of a broad, flat plain gently sloping to the southeast, and intersected by a parallel system of drainage dating from the withdrawal of the ice-sheet. Considerable areas have, as yet, been but partially invaded by the backward erosion of the streams, and the divides are still characterized by flat tops representing the original plain out of which they have been carved.

STRATIGRAPHY OF THE REGION.

Structure.—In this region, the rock floor upon which the drift rests is made up chiefly of the Lower Coal Measure deposits and the Saint Louis limestone. By the erosion of the streams, however, lower formations are frequently exposed so that the area has furnished typical sections of a considerable part of the Lower Carboniferous series. Extensive preglacial erosion has greatly reduced the surface area of the Saint Louis

and Coal Measure rocks. They now occur in three areas separated by extensive drift-filled preglacial channels. In Van Buren county no decisive evidence of similar channels has been obtained, but from the great thickness of drift shown by certain well records, and from other indications, there is reason to suspect that Fox River occupies approximately the position of an older stream.

Description of sections.—In the Illinois Geological Report, Vol. I., Worthen has included the Warsaw beds in the Saint Louis group and gives the following section of these rocks at Warsaw:

I. SECTION AT WARSAW.

1. Concretionary brecciated limestone,	30′
2. Arenaceous limestone,	10′
3. Blue argillaceous shales and limestones,	30′
4. Magnesian limestone,	12′
	82′

In this section, Nos. 2, 3 and 4 constitute the Warsaw as established by Hall. At Keokuk the beds between the Geode Shales and the Coal Measures are as follows:

II. SECTION AT KEOKUK.

1. Brecciated limestone; the fragments composed of gray compact limestone, sometimes firmly cemented by similar calcareous material, in other cases with the interstices filled with green clay,	10′–30′
2. Calcareous sandstone; blue, weathers brown; in some cases quartz grains numerous and coarse,	8′
3. Blue argillaceous shale with thin variable beds of limestone, the latter subcrystalline and fossiliferous,	20′
4. Magnesian limestone, brownish gray; in some places coarse subcrystalline, in others fine and of a bluish color; weathers to a yellowish brown,	4′
	62′

The calcareous sandstone (No. 2) corresponds to No. 2 of the Warsaw section and is quarried to some extent both above and below the city. The limestones of Nos. 3 and 4 are marked by the presence of numerous fossils among which the remains of Bryozoa, notably Archimedes and Fenestella, are especially abundant. The beds 2, 3 and 4, representing the original Warsaw, have a marked correspondence to the equivalent deposits at Warsaw though considerably reduced in thickness.

Excellent exposures of the Saint Louis limestones occur at various localities on East Sugar Creek:

III. EAST SUGAR CREEK SECTION.

1.	Compact light gray limestone; breaks with conchoidal fracture,	3′
2.	Light brown friable sandstone,	10′
3.	Compact fine-grained limestone,	1′
4.	Friable calcareous sand,	10′
5.	Brecciated limestone; fragments mostly of light-colored compact limestone well cemented by similar calcareous material,	15′
6.	Brown magnesian limestone, slightly arenaceous in places; somewhat thick and irregularly bedded; contains lenticular masses of brecciated limestone similar to No. 5,	10′
7.	Blue arenaceous shale; includes fragments of chert and siliceous limestone,	6′
		55′

This section occurs on the branch of East Sugar Creek flowing through West Point township. The brecciated limestone is rather coarsely stratified, and appears smooth and waterworn in places. At one point a looser aggregate of the same character occupies what appears to be a channel eroded in the more compact breccia. The lenticular masses occurring near the base of the magnesian beds do not differ essentially from the main mass of the brecciated rock. Near the top of the magnesian beds, however, the lenticular masses are composed, in part, of fragments resembling the brown magnesian limestone itself. At Graner's quarry in the N. W. ¼ Sec. 30, T. 68 N., R. 5 W., the beds above the brecciated limestone are represented by sixteen feet of coarse granular limestone, or calcareous sand rock, cross bedded and prominently ripple marked. Beneath the granular limestones there are about eight or ten feet of brecciated limestone followed downward by the same thickness of brown magnesian limestone. A shaft and drill hole penetrated thirty feet of shale below this bed, the upper ten of which was destitute of geodes and apparently represents the Warsaw shales.

One-half mile southwest of the quarry the granular limestones are replaced by fine compact gray limestone containing more or less nodular chert.

At a small quarry one and one-half miles south of Donnellson,

the granular limestones are seen underlain by the brecciated limestone and this by brown magnesian limestone in which *Lithostrotion canadense* was found. This bed is arenaceous in appearance and is locally termed a sandstone.

On the Des Moines River, about a mile below Belfast, the calcareous sandstones represented by No. 2 of the Keokuk and Warsaw sections are twenty to twenty-five feet thick and change locally to blue arenaceous shale. About a half mile east of this locality, a quarry shows the following arrangement:

IV. SECTION AT DEAMUDE'S QUARRY.

1. Clay, yellow above, red below,	6′
2. Brecciated limestone with pockets of green clay,	20′
3. Hard blue limestone varying to blue arenaceous shale or shaley sandstone,	3′
4. Sandstone, blue calcareous, varying locally to arenaceous shale; quarried,	8′
5. Blue shale,	15′
	52′

Some closely related exposures on a small creek about a mile west of Belfast are especially instructive. Beginning near the mouth of the stream and following up its course the following sections were taken a quarter of a mile apart. In the intervening spaces, the rocks are not exposed.

V. SECTIONS NEAR BELFAST.

A.

1. Concealed.	
2. Sandstone, blue, weathering brown; somewhat thin bedded and micaceous in places; corresponds to the sandstones below Belfast,	15′
3. Blue argillaceous shale; no geodes,	5′+
	20′+

B.

1. Concealed.	
2. Brecciated limestone; light-colored,	8′
3. Brown magnesian limestone, concretionary, some layers more compact; blue,	12′
4. An irregular bed of fragmentary limestone and shale, more or less arenaceous,	6′
5. Blue argillaceous shale, equivalent of No. 3 above,	1′
	27′

C.

1.	Concealed.	
2.	Hard, white granular limestone in thin flaggy beds; the lower layers contain grains of quartz, - - - - - - -	12′
3.	Hard, compact gray limestone, breaks with conchoidal fracture, -	10′
4.	Brown magnesian limestone in thick, somewhat undulating beds, -	10′
		32′

Taking the blue shale as a guide, it is evident that the sandstone in Section A has graded into the magnesian limestones in Section B. In Section C the compact and granular limestones replace the brecciated beds of Section B. The compact limestone is identical with the fragments composing a large part of the brecciated rock and evidently represents an undisturbed portion of the original formation.

Some excellent exposures of the Saint Louis limestones occur near the mouth of Rock Creek:

VI. ROCK CREEK SECTION.

1.	Concealed.	
2.	Hard, gray compact limestone; contains *Rhynchonella ottumwa, Spirifer, Keokuk var. littoni*, - - - - - -	6′
3.	Brown, friable quartzose sandstone, - - - - -	4′
4.	Brecciated limestone, - - - - - - -	20′
5.	Brown, magnesian concretionary limestone in massive beds; contains *Lithostrotion canadense*, - - - - - - -	15′
6.	Bed of blue sandy shale, blue grit sandstone, and buff-colored magnesian limestone confusedly mixed together; fragments of chert imbedded in the arenaceous shale, - - - - - -	6′
7.	Blue shale interbedded with thin layers of blue fossiliferous limestone,	16′
		61′

The lower bed (No. 7) is referred to the Warsaw shales. The sandstone No. 3 develops locally to twenty and twenty-five feet, while opposite Keosauqua it contains considerable quantities of calcareous matter and, in places, thin ledges and fragments of limestone. The compact limestone above increases to about fifteen feet in thickness near Keosauqua, where it is quarried to some extent. The heavy-bedded concretionary limestones, No. 5, graduate locally into arenaceous limestones and calcareous sandstones. This gradation may be observed in the basal portion in tracing the formation along the bluffs below Keosauqua. At

Price's quarry, on a small branch of Chequest Creek, west of Pittsburg, and on Bear Creek opposite Bentonsport, the sandstones of this horizon are sufficiently developed to furnish a good quarry stone. It consists of blue calcareous sandstone which weathers brown on exposure. In places it is more or less magnesian.

Correlation.—In Van Buren county, the arenaceo-magnesian beds constitute the base of the Saint Louis group. They have a greater development there than in Lee county where they are replaced partially or wholly by the brecciated limestone. They are represented at Keokuk, Warsaw, Sonora (Ill.) and elsewhere by arenaceous beds originally included in the Warsaw group.

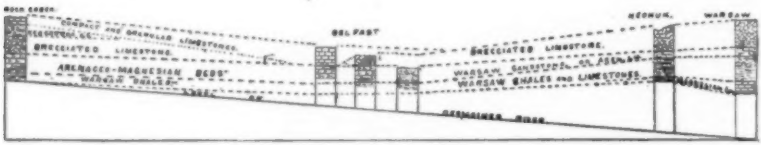

FIG. 2.—Correlation of sections at Warsaw, Keokuk, Belfast and Rock Creek.

The relation of the various beds is shown in the following combined section (Fig. 2) of exposures at Warsaw, Keokuk, Belfast and Rock Creek, while the accompanying table shows the classification here adopted compared with those previously given.

CLASSIFICATION OF THE FORMATIONS OF THE KEOKUK AND SAINT LOUIS GROUPS.

Gordon	Formations	Hall	White	Keyes
L. C. M.	Lower Coal Measures	L. C. M.	L. C. M.	L. C. M.
Saint Louis	Compact and Granular Limestones (Keosauqua S.S.)	St. Louis	Saint Louis	St. Louis
	Brecciated Limestone			
	Arenaceo-Magnesian Beds	Warsaw		Keokuk
Keokuk	Warsaw Shales and Limestones			
	Geode Shales	Keokuk	Keokuk	
	Keokuk Limestone			

CHARACTERISTICS OF THE FORMATIONS.

The Warsaw shales and limestones.—A consideration of the given sections will show that, at the original locality, the Warsaw group consisted of three members, viz., a bed of magnesian limestone at the base, arenaceous limestone or calcareous sandstone at the top with argillaceous shales, including thin and variable beds of limestone between. Of these the last is the most persistent. The basal division which is twelve feet thick at Warsaw diminishes to three or four feet at Keokuk and is not recognized north of that place. The middle division, however, unchanged in character but greatly diminished in thickness, is recognized at Farmington, Rock Creek and doubtfully at several other localities. The shales and limestones evidently thin out entirely near the north line of Lee county. The formation is prominently characterized by Bryozoa, among which species of Archimedes, Fenestella and other reticulated forms are conspicuous. With these are associated other forms constituting a somewhat peculiar assemblage of fossils, though on the whole allied to those of the Keokuk group. In the Illinois reports, the peculiarity of the fauna is admitted but is considered of somewhat local development, and is attributed to local conditions of sedimentation rather than to any specific change in the character of the fauna. A somewhat similar assemblage of fossils at Bloomington and Spergen Hill, Indiana, was referred to by Hall as proving the existence of these beds in that state. As later collectors have referred the fossils obtained from these beds to the horizon of the Saint Louis limestone without specific designation of the beds from which they were obtained, new collections must be made before the exact relations of these deposits can be considered established.

Evidently, however, the formation is not of wide extent and probably represents only a comparatively local development of the geode shales into which they grade below. It is suggestive in this connection that the geode shales have their most characteristic development coincident with that of the Warsaw shales and limestones, and both soon lose their distinctive characters

and are traced with difficulty toward the south. The oölitic limestone of Monroe county, Indiana, generally correlated with this formation, has been found to occur in an oblong basin or trough, pointing to local sedimentation.

Arenaceous Limestone of the Warsaw.—The arenaceous member at the top of the original Warsaw group has evidently been the source of much of the confusion in the stratigraphy of this region. At Keokuk, it consists of a blue calcareous sandstone in a single massive bed eight feet thick. It contains large white quartz grains scattered through the finer arenaceous material, the whole being firmly cemented by a large amount of calcareous matter. Locally, the quartz grains become large enough to be called pebbles. With the decrease of the arenaceous element, the rock grades gradually through arenaceous to magnesian limestone. All of these phases may occur together in alternate bands. As a whole, the rock weathers to a characteristic brown from the oxidation of the iron, which takes place more rapidly in the arenaceous parts, giving the rock a banded appearance. At Sonora quarry, four miles below Nauvoo, this formation is well developed. It becomes more shaley toward the north end of the quarry and grades horizontally into brown, cellular magnesian limestone. At the Pontoosac quarries above Niota, Ill., the formation has a maximum development of forty feet at one point in the quarry, rapidly diminishing away from this locality to about fifteen feet. Though having the appearance of a sandstone, and called such, analysis shows it to contain only 7 per cent. of sand, a like proportion of clay, and 60 per cent. carbonate of lime, while the remainder is undetermined, but probably consists principally of magnesian carbonate. Cavities lined with spar and sometimes containing Millerite, are occasionally found in the lower part. In places the arenaceous character is replaced by hard, bluish magnesian limestones. The formation rests upon blue shale of which thirty-three feet was penetrated by drill. The surface of the shale is noticeably irregular and the demarkation between it and the formation above is pronounced. At Deamude's quarry, the character of the formation is very sim-

ilar to that at Pontoosac. The sandstones at the same horizon on Bear and Price's creeks in Van Buren county differ in no important respect from those in the vicinity of the Mississippi.

The brown magnesian limestones.—At numerous places on the Des Moines River and its tributaries above Belfast, brown magnesian concretionary limestone is seen resting upon the Warsaw shales and limestones, though separated from them by a more or less disturbed layer of soft, earthy limestone and arenaceous shale inclosing fragments of chert. The magnesian limestones are disposed in thick undulating beds, and contain considerable concretionary chert. These chert nodules average about one to two inches in diameter, and on the decay of the limestone show a thin layer of green clay lining the cavity inclosing the nodule. The nodules usually contain fossil remains in abundance, generally in a fragmentary condition, though the limestone in which they occur may show very little indication of life. The limestone is usually blue on first removal, but quickly oxidizes to a rusty brown color. In texture, the rock is usually more or less vesicular but varies to a compact somewhat earthy limestone. The latter phase especially characterizes one or two thin ledges. These ledges break down more rapidly on exposure and do not weather brown as in the case of the more vesicular portions. The latter become arenaceous locally, as on the Des Moines below Keosauqua, and on Lick Creek above Kilbourne. At the latter place, the indications of cross bedding are marked. The arenaceous element is observed chiefly in the lower beds. The lowest bed is marked frequently by a large proportion of siliceous matter in irregular masses. These masses are nearly pure white silica and are sometimes disturbed and worn as if by wave action subsequent to consolidation. The greatest thickness of these limestones observed is twenty feet. On Chequest Creek, they are seen to grade upward into a compact, buff-colored limestone known locally as Chequest marble. *On Price's Creek west of Pittsburg, the lower layers grade horizontally into well marked sandstone indistinguishable from the arenaceous limestone of the Warsaw beds at Belfast, Sonora and elsewhere.* The brown limestones are marked

by the presence of the well known and characteristic coral *Lithostrotion canadense*, but this fossil has not been observed in the arenaceous portions. An analysis of the magnesian limestone by Owen[1] shows it to be a nearly pure dolomite, consisting of 56 per cent. carbonate of lime and 37 per cent. carbonate of magnesia. Additional analyses are now being made of these and associated rocks by the Iowa survey.

Compact gray limestones.—Overlying the magnesian limestones at Belfast and on Price's Creek, but usually separated elsewhere by the brecciated formation, is a white or bluish gray compact limestone which breaks with conchoidal fracture, and is usually characterized by brachiopods in greater or less abundance. Among these *Spirifera Keokuk, var. littoni, Rhynchonella ottumwa, Productus tenuicostus* are common. The limestone is a nearly pure carbonate of lime, fine grained and brittle, and corresponds in nearly every particular with the character of the Saint Louis limestone as originally described by Shumard. It is sometimes affected by considerable quantities of nodular chert, in consideration of which Owen termed it the Upper Concretionary limestone. In thickness this formation does not usually exceed fifteen feet.

That portion of these beds which rests directly upon the magnesian limestones on Price's Creek, while in the main similar to the higher strata, differ in being of a darker color, and it is from one of these that the "Chequest marble" is obtained, a block of which was the contribution made by the citizens of Van Buren county to the Washington monument.

Granular limestone.—Associated with the compact limestones in places is a formation of granular white or gray limestone which is remarkable for the pronounced exhibition of cross bedding and ripple marks. These beds evidently represent the limestones from this region which have been described as oölitic, but they are rather of a granular or sandy texture. In some places they contain grains of quartz, though for the most part composed of nearly pure carbonate of lime. Intercalated with the thin flaggy

[1] OWEN, D.D.: Geol. Surv. Wis., Ia. and Minn.

layers of granular limestone, however, one or more thin beds of a purer, fine and compact limestone occur which are especially valuable for the manufacture of lime. The granular limestones are well exposed at Graner's quarry (p. 295) and elsewhere. At Belfast they are seen resting upon the compact limestones, the whole constituting a thickness of twenty-two feet. This formation is sometimes found in small lenticular patches in the brecciated limestone, and in some cases a limited development of true oölitic limestone occurs under similar conditions, but it is not common.

Brecciated limestone.—This constitutes the most generally recognized phase of the Saint Louis group in Iowa. Usually it consists of ten to twenty feet of limestone breccia or conglomerate in which the fragments are of the compact variety noted above, more or less completely cemented by similar calcareous material. In its maximum development it is from 50 to 75 feet thick, the brecciated character in these cases evidently involving all of the preceding formations to the base of the Saint Louis group. In these exposures, as, for example, near the mouth of Reed's Creek in Van Buren county, at Croton, and elsewhere, the lower portion is seen to consist of coarse fragments of the arenaceo-magnesian limestones, and their related sandstones, loosely piled together, and the interstices filled with green clay. The whole takes on a rude stratification, while somewhat persistent but decidedly undulating beds occur at irregular intervals. Upwards the breccia becomes more compact and firmly cemented, and is composed chiefly of the compact white or gray limestones sometimes including the granular type. Away from these areas of greatest disturbance, the lower portion is soon replaced by undisturbed strata of the brown Lithostrotion formation while over this the lighter colored, more compact breccia extends itself in varying thickness. It fails entirely in places, as already noted, and its place is occupied by the compact gray limestones in undisturbed beds. These limestones differ from those which elsewhere rest *upon* the brecciated formation in being of a somewhat darker shade. The fragments of limestone composing the breccia are frequently waterworn, but the wearing has seldom

proceeded very far. In some places it may, with propriety, be called a limestone conglomerate, but from the more or less angular character of the fragments the term breccia is more generally applicable. In some exposures thin lenticular beds of breccia, identical in every respect with the main formation, are intercalated between thick layers of the brown concretionary limestone.

The most prominent fossil found in the brecciated limestone is *Lithostrotion canadense*, though this is not abundant, and occasionally another coral like *L. proliferum*. The latter has also been found in the compact limestones at the horizon of the brecciated formation, where this formation is absent. The brecciated limestone characterizes the Saint Louis throughout nearly the whole of its extent in southeastern Iowa. Except where removed by erosion, and at a few localities (Section V.) where it appears never to have been formed, it constitutes a prominent feature of nearly all the rock exposures in Lee and Van Buren counties. It varies in thickness from five to seventy-five feet, but is usually ten to twenty feet thick.

Keosauqua sandstone.—In the area occupied by the Oxbow bend of the Des Moines, a bed of rather coarse brown more or less friable sandstone is intercalated between the brecciated limestone and the compact gray limestone above. Below Keosauqua it is seen at several places resting upon the brecciated formation with a greater or less thickness of the compact limestone resting upon it. Above that place it is seen in the south bank of the river but little above the level of the water where the basal portion is composed in part of isolated layers of limestone inclosed in the sandstone. Opposite Keosauqua the deposit is much disturbed both in character and stratification, in some cases having a large amount of fine calcareous material mingled with the sand which is very irregularly lithified, while in other cases it contains occasional beds of limestone. The overlying limestone has been removed by erosion in some places, leaving the sandstone at the surface. The area thus exposed, however, is small. In some cases the removal took place prior to the deposition of the Coal Measures so that now these formations rest

directly upon the sandstone. An exposure of this kind occurs on Coates Creek about four miles north of Bonaparte. In thickness the formation varies from a few feet to twenty or twenty-five feet.

The area over which this deposit is recognized is limited. It is not known outside of Van Buren county except at one locality in Lee shown in Section III. (p. 294). In Van Buren county the sandstone appears to be directly related to the Bentonsport arch, evidently lapping up against it in the form of an off-shore deposit and thinning out away from the axis of uplift. In origin and occurrence it is clearly related to the brecciated limestone and is seemingly only a phase of that formation due to local conditions attending deposition. The relations of the various beds is shown in the accompanying hypothetical section from south to north.

FIG. 3.—Section from south to north showing the relations and variations of the Saint Louis limestone: (1) Geode bed (Keokuk). (2) Warsaw shales and limestones (Keokuk). (3) *a*. Arenaceo-magnesian beds, *b*. Brecciated limestone, *c*. Keosauqua sandstone, *d*. White or gray compact and granular limestones. (4) Lower Coal Measures.

UNCONFORMITIES.

Unconformity below the Saint Louis.—It has been shown by White[1] that while the borders of the Kinderhook, Burlington and Keokuk formations recede, showing a gradual withdrawal of the sea to the south, the Saint Louis limestone overlaps these and reaches nearly as far north as does the Kinderhook. "Consequently these beds (Saint Louis) are recognized as resting unconformably upon all the rest of the Lower Carboniferous in Iowa."[2]

Hitherto no evidence of unconformity at this horizon has been reported from southeastern Iowa. In the nature of the

[1] Geology of Iowa, 1870, Vol. I., p. 226.

[2] C. R. KEYES has recently found beds with typical Burlington crinoids and other fossils in Keokuk, Marshall and Humboldt counties, proving the extension of these beds nearly to the Minnesota line. Hence the overlap of the Saint Louis is probably not so great as White supposed it to be.

case the evidence would be imperfect since the southern boundary of the state apparently marks the extreme limit to which the sea withdrew at the close of the Keokuk epoch. At several localities, however, we have noted a disturbance in the stratification at the base of the arenaceo-magnesian beds which apparently represents the break referred to. It is usually marked by a confused commingling of arenaceous, shaley and calcareous material inclosing fragments of chert, broken shells, etc. It appears in the Rock Creek section (p. 297) and at several other places in Van Buren county, also on East Sugar Creek in Lee county. The arenaceous deposits of the arenaceo-magnesian beds are also sometimes marked by small quartz pebbles in a more or less calcareous matrix, while the cross bedding in the sandstones indicate proximity to the shore line or at least shoal water.

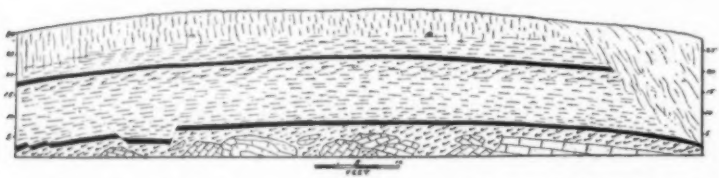

FIG. 4.—Section on Bear Creek, Van Buren county (Sec. 10, T. 68, N. R. 9, W.), showing unconformity of Lower Coal Measure upon Saint Louis limestone.

Moreover, the manner in which the Warsaw shales and limestones below thin out northward offers confirmatory evidence of unconformable relations.

Unconformity above the Saint Louis.—At the close of the Saint Louis epoch the sea again receded, evidently quite rapidly, leaving no enduring evidence of the next succeeding formation (Kaskaskia) which lies 100 miles south of the Iowa boundary. During the Kaskaskia epoch the Iowa region was subjected to extensive erosion, and, on the irregular surface thus formed, the Coal Measure formations were subsequently deposited. Exposures showing this erosion unconformity occur at numerous places in southeastern Iowa. Figure 4 represents an exposure of this character on Bear Creek. The Coal Measure rocks are

here seen resting upon the granular limestones which show various stages of disintegration and decomposition. The clays resting upon the limestones and filling the interstices between the oxidized limestone fragments is evidently the residual product of the decay of the limestones.

About one-half mile west of Rock Creek quarry, the shales of the Coal Measures rest upon the magnesian limestone of the arenaceo-magnesian beds, apparently indicating a channel of erosion at this point (Fig. 5).

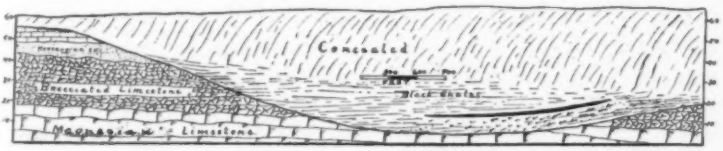

FIG. 5.—Section near the mouth of Rock Creek (Sec. 21, T. 69, N., R. 9, W.) showing eroded surface of the Saint Louis limestone.

One of the best exposures is at the Sonora quarries where the brecciated limestone is entirely cut out by the descent of the Coal Measure rocks (Fig. 6).

FIG. 6.—Section along face of Sonora (Ill.) quarry showing unconformity of Coal Measures upon Saint Louis limestone.

ORIGIN OF THE BRECCIATED CHARACTER OF THE SAINT LOUIS LIMESTONE.

The origin of the brecciated character often prevalent in limestone formations has never been satisfactorily explained. The explanations that have been offered are:

(1) Wave action upon a rock-bound coast.

(2) The systematic alternation of vigorous and quiet action

of wind waves taken in connection with tidal oscillation in regions where the sea bottom is subjected to wave action at low tide.

(3) Wave action especially facilitated by the development of coral reefs.

None of these is sufficient alone to account satisfactorily for the brecciated limestone of the Saint Louis beds, though in each case favored to a certain extent by the character of the formation. The existence of coral reefs contemporaneous with the formation of this deposit, though not clearly proven, is supported by many structural details. In lithological character there is a striking likeness between these deposits and those of modern coral reefs so well described by Dana. Professor Chamberlin has described a similar character of sedimentation in the Niagara limestone of Wisconsin[1] which he ascribes to a like origin. The abundance of life which characterizes the Niagara reefs in Wisconsin, however, does not appear in the brecciated areas of the Saint Louis limestone in Iowa. While corals are present, they are not especially abundant and no coralline masses standing as they grew have been observed.

The alternations sometimes seen between the brecciated and undistributed portions apparently favors the view that the sea bottom suffered an alternation between vigorous and quiet conditions during the time of its deposition. This may be ascribed (1) to oscillations of the earth's crust, or (2) to tidal oscillation where the sea bottom lies just below low tide.

While crustal movements were evidently in progress during the Saint Louis epoch, the acceptance of this view to account for these minor changes would imply a delicacy of adjustment scarcely in harmony with the character of the forces involved. Professor Chamberlin has called attention[2] to the effect of systematic alternation of wind waves taken in connection with tidal oscillation in accounting for the formation of brecciated limestone. In those areas where the depth of water is such that the sea bottom

[1] Geology of Wisconsin, Vol. I., pp. 183–186.

[2] Geology of Wisconsin, Vol. I., p. 168.

is subjected to wave action at low tide it is conceivable that the alternation of forcible and quiet action might constitute an essential factor in the formation of extensive sheets of brecciated limestone. In its advance upon the land at the close of the Keokuk epoch the sea would doubtless encounter irregularities of the surface, some of the elevations reaching nearly or quite to the surface of the water. The Bentonsport arch apparently represents an area of this character. The first deposits would contain more or less arenaceous material derived from the receding shore. Owing to the prevailing calcareous character of the preceding formations, however, the arenaceous material would be insufficient to constitute a widespread sandstone formation. These conclusions are supported by the lithological character of the arenaceo-magnesian beds, the lower portion of which is generally more or less arenaceous and in places decidedly so. The calcareous mud derived by the trituration of the waves upon those parts of the sea bottom within their reach would be deposited in the quiet lagoons or carried out into deeper water to form the fine-grained compact limestones. As the brecciated formation is made up chiefly of fragments of these fine-grained rocks, it is evident that solidification must have taken place very quickly. The presence of lenticular masses of breccia made up of fragments of these fine-grained white or gray limestones interlaid with the massive brown arenaceo-magnesian beds implies that their formation was going on contemporaneously with the sedimentation of the latter beds. Their isolated occurrence, however, as well as their position below the main mass of breccia is not readily explicable unless they represent the thinning out of local masses exposed by tangential erosion. It has been suggested that similar occurrences were due to transportation by shore-ice.[1] The assumption of this agency, however, would preclude the acceptance of coral growth as a factor in the formation of the brecciated limestone, as it implies conditions of temperature inconsistent with the development of reef-building corals.

[1] WALCOTT, C. D.: Bull. Geol. Soc. Am., Vol. V., p. 197.

Dolomitization.—There is a marked difference in lithological character between the arenaceo-magnesian beds and the overlying limestones. The former are decidedly magnesian and in some cases dolomitic, while the latter are almost entirely calcareous. Where the brecciated bed is absent there appears to be a gradation between the two. The explanations which have been proposed to account for dolomitization are:

(1) Chemical precipitation or sedimentation.

(2) Leaching of carbonate of lime from a magnesian limestone subsequent to solidification.

(3) Replacement of some of the lime by magnesia subsequent to solidification.[1]

From the record of observations it seems probable that all of these processes have taken place. With regard to the first view it has been shown by Dana[2] that while "corals themselves contain very little carbonate of magnesia, magnesia is largely present in some specimens of the rock." The coral sand and some of the compact limestones, however, are said to have very little or no magnesia. The conclusion is drawn that the introduction of the magnesian element has taken place (1) in sea waters at the ordinary temperature and (2) without the aid of any mineral waters except the ocean. The change is thought to have taken place in contracting and evaporating lagoons in which the magnesian and other salts of the ocean were in a concentrated state. That dolomite is essentially a littoral deposit has been advocated by Calvin,[3] while Geikie says that while some dolomites may have been formed by chemical precipitation in inland lakes and seas, others may have been formed by the action of magnesian salts of sea water upon organic limestones already formed.[4] The relations of the magnesian and compact limestones in southeastern Iowa favor the conclusion that they were formed under essentially the same conditions. As the magnesian character

[1] HOPKINS, T. C.: Geol. Sur., Ark., 1890, Vol. IV., p. 38.

[2] Corals and Coral Islands, p. 393.

[3] American Geologist, Vol. I., p. 30, and Vol. II., p. 36.

[4] Text-book of Geology, p. 296.

appears more pronounced in areas affected by brecciation and has not been noted as far south as St. Louis, there is a strong presumption that the conditions attending the formation of brecciated limestone exercised a controlling influence in effecting the transformation of the rock. The limestone of the Niagara reefs of Wisconsin are dolomitic, as indeed are nearly all those found in that state.[1] The available evidence, therefore, is apparently in favor of Calvin's conclusion that dolomites are essentially off-shore products.

C. H. GORDON.

[1] Geology of Wisconsin, Vol. I., p. 303.

ALGONKIAN ROCKS OF THE GRAND CANYON OF THE COLORADO.

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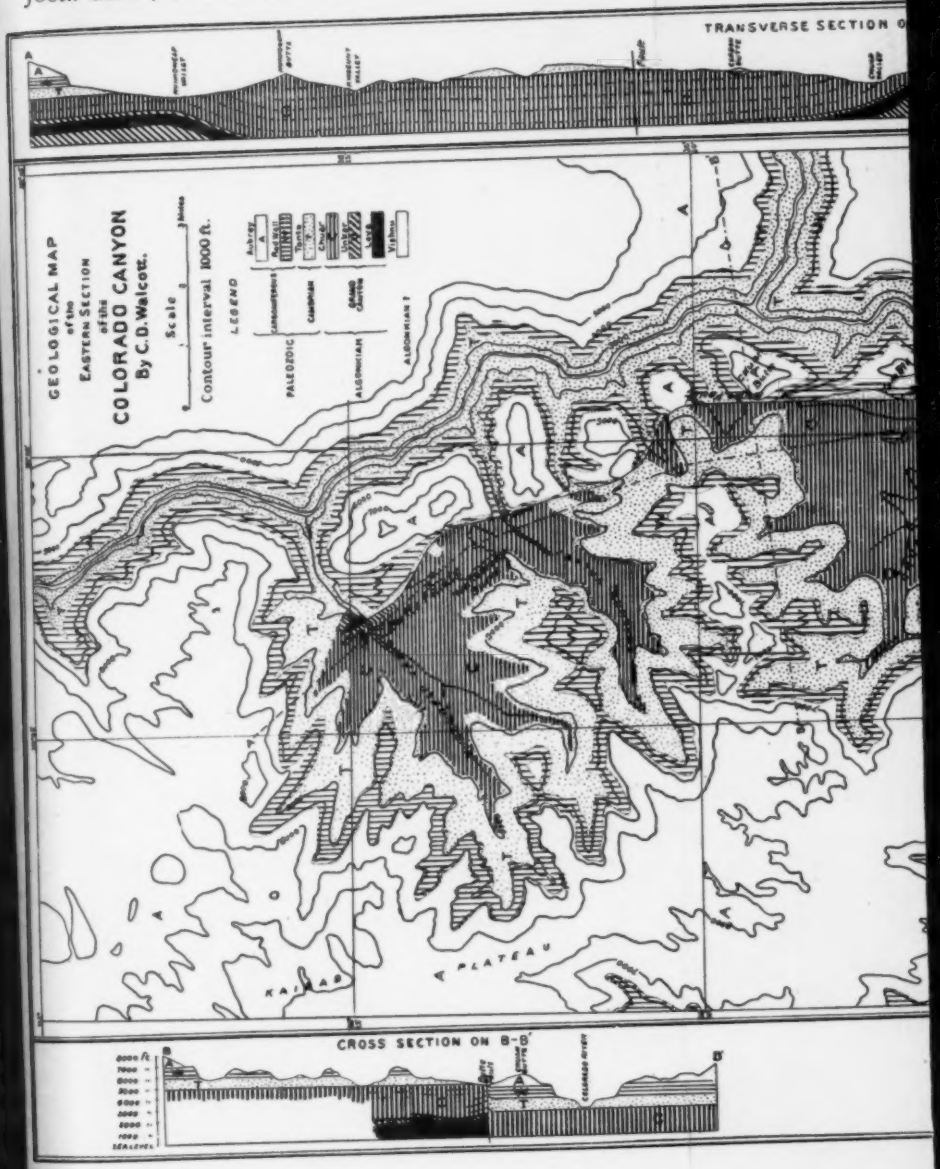
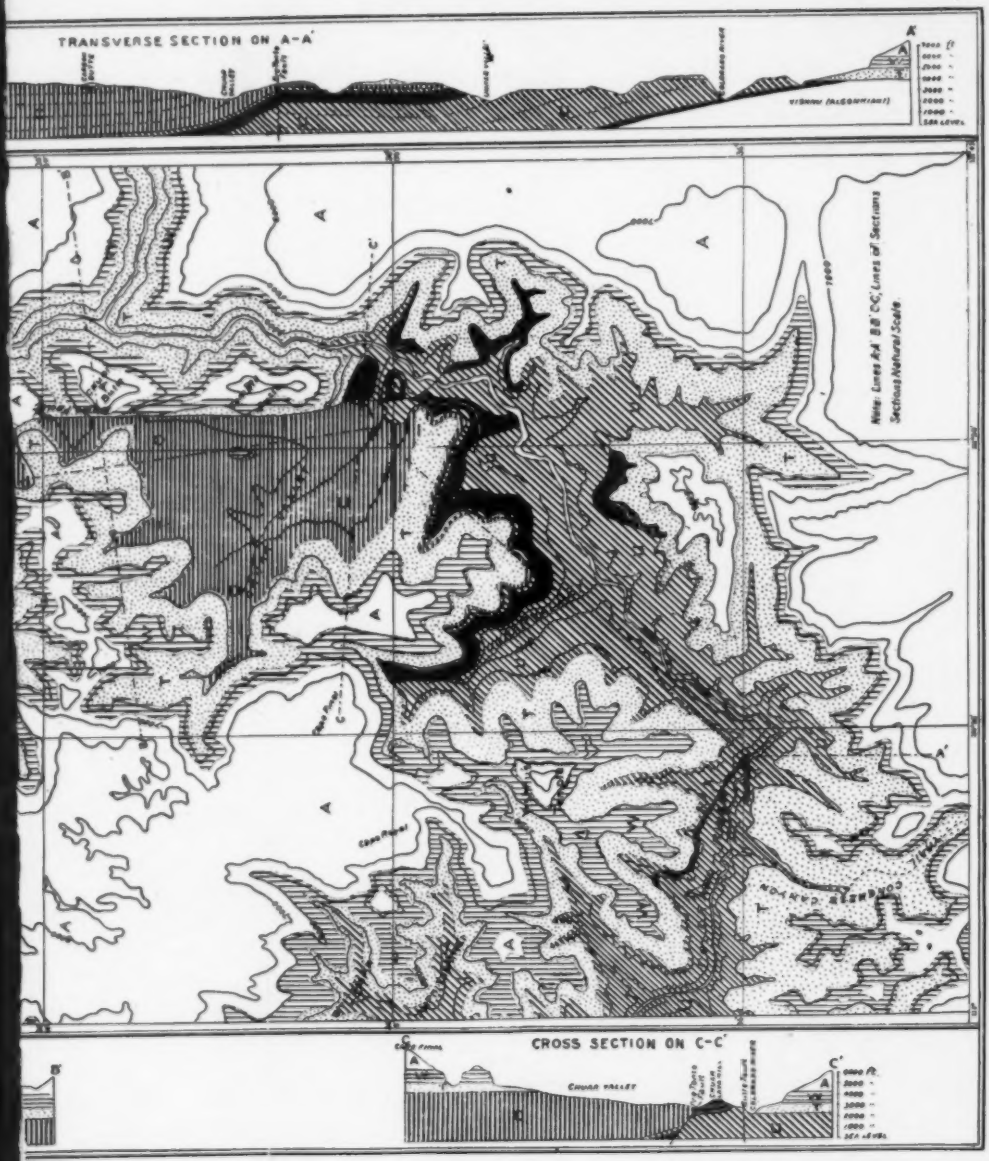
INTRODUCTION.

THE Algonkian rocks of the Grand Canyon are unique among the known unconformable pre-Cambrian rocks both of America and of Europe. Nowhere else has the geologist an equal opportunity to study such a series of ancient sediments nearly as they were laid down on the bed of the Algonkian sea. At no other known locality are there such extended and complete exposures of all the beds forming a great series of pre-Cambrian strata, permitting of such certainty in the determination of stratigraphic position and succession.

The first recorded notice of these rocks is that by Major J. W. Powell in the account of his famous explorations of the Colorado River of the West and its tributaries. He says in his report of 1875, page 212, that above the granites there are beds of hard, vitreous sandstone, of many colors, that add but little more than 500 feet to the height of the walls, and yet, owing to their nonconformity with the overlying Carboniferous rocks, they are 10,000 feet in thickness. On page 213 we learn that the rocks unconformably beneath the sandstone series are composed of metamorphosed sandstones and shales which have


TRANSVERSE SECTION
GEOLOGICAL MAP
of the
EASTERN SECTION
of the
COLORADO CANYON
By C.D. Walcott.
Scale
Contour interval 1000 ft.
LEGEND
PALEOZOIC
ALGONKIAN
ARCHEAN
KAIBAB
PLATEAU
CROSS SECTION ON B-B'
SEA LEVEL


TRANSVERSE SECTION ON A-A'
CROSS SECTION ON C-C'
Note: Lines A-A' B-B' C-C' Lines of Sections
Sections Natural Scale

been folded so many times, and so squeezed and heated, that their original structure as sandstones and shales is greatly obscured or entirely destroyed. Further, after these beds were deposited, after they were folded, and after they were deeply eroded, they were fractured, and through the fissures came floods of molten granite, which now stands in dikes, or lies in beds, and the metamorphosed sandstones and shales and the beds of granite present evidence of erosion subsequent to the periods just mentioned yet antecedent to the deposition of the nonconformable sandstones.

In a report on the geology of the eastern portion of the Uinta Mountains, etc., 1876, page 70, Major Powell's summary of the Grand Canyon Group is as follows:

> The Grand Canyon Group rests conformably upon the crystalline schists. The evidence of this is complete, for the lower sandstones and conglomerates first filled the valleys and then buried the hills of schistic rocks, and these conglomerates at the base of the group are composed of materials derived from the metamorphic hills about; and hence metamorphism was antecedent to the deposition of the conglomerates.
>
> The plane of demarkation separating this group from the Tonto Group is very great. At least 10,000 feet of beds were flexed and eroded in such a manner as to leave but fragments in the synclinals. Then followed a period of erosion during which beds of extravasated material were poured over the fragments, and these igneous beds also were eroded into valleys prior to the deposition of the Tonto Group.
>
> Fossils have been found at the base of the Grand Canyon series, but they are not well preserved and little can be made of them. Still, on geological evidence, I am of the opinion that these beds should be considered Silurian.

The subjacent Grand Canyon schists are referred to the Eozoic. This is followed by a statement that the grouping should be considered merely tentative; that it may need some modification, or possibly radical changes.

When describing the unconformity between a horizontal series of rocks forming the upper 4000 feet of the canyon walls and the subjacent unconformable series, Captain C. E. Dutton stated, in his Tertiary History of the Grand Canyon District, 1882, page 179, that the thickness of the lower series must be very great—at least 6000 feet, that Major Powell's estimate of 10,000 feet is

apparently justified, and that the age of the series is probably Silurian; also that Devonian beds may be found in its upper part, but all that he could say then was that they are pre-Carboniferous. He called attention to some layers among the higher beds of the series which he did not hesitate to pronounce volcanic rocks—basalts or diabases. They are coal black and interbedded with the Upper Silurian (?) strata, but whether they are intrusive sheets or contemporaneous coulées outpoured while the rocks were accumulating, he could not say.

During the winter of 1882–83 I studied in detail the Grand Canyon series of Powell, and found that it was, as stated by the latter, unconformably beneath the Tonto sandstone. The lava beds, however, were found to be interbedded and contemporaneous with the deposition of the Grand Canyon terrane and 6000 feet below the summit of the series. In a preliminary note published in 1883, the Grand Canyon series of Powell is divided into a lower or Grand Canyon group and an upper, the Chuar group.[1]

As traces of fossils were found in the Chuar terrane, it and the Grand Canyon terrane were referred to the Lower Cambrian. The subjacent unconformable strata were referred to the Archean, and by reason of stratigraphic position they were tentatively correlated with the Keweenawan group of Wisconsin.[2]

In 1886 the Grand Canyon and Chuar terranes were referred to a pre-Cambrian series of rocks;[3] and in 1890, in describing the Butte fault, a diagrammatic section[4] and several detailed sections that included portions of the Chuar and Unkar terranes were published.[5]

In his correlation paper on the Archean and Algonkian rocks,[6]

[1] Pre-Carboniferous strata of the Grand Canyon of Colorado: Am. Jour. Sci., Vol. XXVI, 1883, p. 440.

[2] *Loc. cit.*, p. 441.

[3] Am. Jour. Sci., Vol. XXXII, 1886, p. 144; Bull. U. S. Geol. Survey No. 30, 1886, p. 41.

[4] Tenth Ann. Rept. U. S. Geol. Survey, 1890, p. 551.

[5] Bull. Geol. Soc. Am., Vol. I, 1890, pp. 51–56.

[6] Bull. U. S. Geol. Survey No. 86, p. 507.

Professor C. R. Van Hise gives a summary of the Algonkian rocks of the Grand Canyon of the Colorado, based upon the observations of Powell, Dutton, and Walcott.

GEOGRAPHIC POSITION AND DISTRIBUTION.

That portion of the Grand Canyon of the Colorado in which the Unkar and Chuar terranes and the typical section of the Vishnu terrane of the Algonkian (?) series or rocks are exposed, is situated in northern Arizona, between 36° and 36° 17′ N. latitude and 111° 47′ and 112° 05′ W. longitude. Most of this area is in the valley portion of the canyon, between the mouth of Marble Canyon and a point south of Vishnu's Temple, a little west of where the Colorado River changes its course from south to northwest. It is wholly within the greater depths of the Grand Canyon, east and southeast and south of the Kaibab plateau. The inter-canyon valleys of this portion of the Grand Canyon extend back from three to seven miles west of the river, and are eroded in the crest of the monoclinal fold that forms the eastern margin of the Kaibab plateau. All of the valleys have small lateral canyons that lead into them from the high margin of the plateau. The Chuar terrane is confined almost entirely to the inter-canyon valleys of Nunkoweap, Kwagunt, and Chuar, as shown on the map (Pl. VI.). About four miles below the mouth of the Little Colorado the Unkar strata rise above the river, and rapidly expand so as to form the inner-canyon beneath the Tonto sandstone for a distance of eleven miles down the westward bend of the river, south of Vishnu's Temple. A small outcrop also occurs on the line of the Butte fault, at the lower end of Nunkoweap Valley. In going down the river the Vishnu rocks are first seen south of Vishnu's Temple (36° N. lat., 111° 55′ 30″ W. long.), and they appear to extend down the river to the southwestern side of the Kaibab plateau, nearly to Surprise Valley (lat. 112° 33′). Whether the pre-Tonto rocks near the mouth of the Grand Canyon are a portion of the Vishnu terrane is unknown.

NOMENCLATURE.

The name "Grand Canyon Group" was given by Major J. W. Powell to the series of strata beneath the Tonto sandstone and above the "Grand Canyon Schists." The latter were referred tentatively to the Eozoic,[1] and the 10,000 feet of the "Grand Canyon Group" to the Silurian. Captain Dutton regarded the series as of pre-Carboniferous age, and probably Silurian.[2]

In 1883 I referred the Grand Canyon series of Powell to the Lower Cambrian, and divided it into a lower and an upper group —the "Grand Canyon" and "Chuar," respectively,[3] the name "Chuar" being proposed by Major Powell.[4] In 1886 the reference to the Lower Cambrian was changed to a pre-Cambrian series of rocks,[5] and correlations were made with the Keweenawan series of the Lake Superior region.[6] In a section of the strata of the Grand Canyon District published in 1890, the pre-Tonto strata were referred to the Algonkian group, under the names Chuar, Grand Canyon, and Vishnu, the latter including the strata unconformably beneath the Grand Canyon group.[7]

At the present time it appears to be necessary to return to Major Powell's name, Grand Canyon,[8] as applied to the entire series of strata between the Tonto and the "Grand Canyon Schists," and to give to the lower series the name Unkar, from the valley in which its finest exposures occur. The name Vishnu is retained for the unconformably pre-Unkar strata. The classification, from the Tonto down, will then be:

[1] Geology of the Eastern Portion of the Uinta Mountains, 1876, p. 70.

[2] Tertiary History of the Grand Canyon District, 1882, p. 180.

[3] Am. Jour. Sci., Vol. XXVI., 1883, p. 439.

[4] *Loc. cit.*, p. 440.

[5] Bull. U. S. Geol. Survey No. 30, 1886, p. 41.

[6] Am. Jour. Sci., Vol. XXXII., 1886. pp. 144, 153–157.

[7] Bull. Geol. Soc. Am., Vol. I., 1890, p. 50.

[8] Changing the spelling of "Cañon" to Canyon, in conformity with the decision of the Board on Geographic Names.

CAMBRIAN.	Tonto.	
Unconformity.		
ALGONKIAN.	Grand Canyon.	Chuar.
		Unkar.
Great Unconformity.		
ALGONKIAN (?)	Vishnu.	

STRATIGRAPHIC RELATIONS.

The stratigraphic relations of the Cambrian, Algonkian, and the doubtful Vishnu beds are indicated by the preceding tabulation, and are clearly shown by section A—A′ of the map. Within the Algonkian series there is no recognized interruption in sedimentation between the base of the Unkar terrane south of Vishnu's Temple and the summit of the Chuar terrane at Nunkoweap Butte, with the exception of a slight unconformity by erosion at the summit of the Unkar terrane. At the base of the Unkar terrane there is a bed of conglomerate that rests unconformably on the eroded edges of the indurated sandstones, micaceous schists, and granitic dikes. The unconformity is absolute. (Fig. 1).

From the base of the Unkar terrane south of Vishnu's Temple the strata dip 10° to the northeast, and then, as shown on the map (Pl. VI. and the accompanying section), they flatten out on the line of the divide between Unkar and Chuar Valleys, dip 25° to the north in the heart of Chuar Valley, and thence extend in low, broad undulations to the syncline of Nunkoweap Butte. North of the Butte the strata rise, the dip being from 20° to 25° southeast. The summit of the series is at Nunkoweap Butte, between Kwagunt and Nunkoweap Valleys. From the point south of Vishnu's Temple to where the strata of the Chuar terrane pass beneath the basal beds of the Tonto sandstone, on the north side of Nunkoweap Valley, there is a marked unconformity between the strata of the Grand Canyon series and the superjacent

FIG 1. Unconformity at the base of the Unkar Terrane. Conglomerates resting on the upturned, eroded Beds of the Vishnu Terrane.

Cambrian sandstone. The former were planed off to a baselevel before the deposition of the latter.

CHUAR TERRANE.

The first division of the Chuar terrane is from the summit of Nunkoweap Butte, on the divide between Nunkoweap and Kwagunt Valleys, down the south side of the butte to the base of a massive belt of reddish-brown sandstone. The latter stratum was traced to Chuar Valley, where it caps the lower division of the terrane on the north side of the valley. The lower division terminates in argillaceous shales resting on a massive magnesian limestone south of Chuar Brook.

Section from the Summit downward.

UPPER DIVISION.	Feet.	Feet.
1. *a*. Massive reddish-brown sandstone, with irregular layers of similar color and containing numerous fragments of sandstone-shale of lighter color	125	
b. The sandstones of 1 become shaly near their base and pass into a reddish, sandy, and then argillaceous shale, with a few thin, compact layers of sandstone in the shale	75	200
2. Black, fissile, argillaceous shale, that crumbles on exposure to the weather		225
3. Compact gray limestone in massive layers; buff on weathered surface		50
4. Shale similar to 2		60
5. Gray limestone similar to 3		50
6. Black argillaceous shale, similar to 2 and 4		140
7. Hard buff limestone, with irregular oölitic, cherty bands that at times constitute most of the stratum		4
8. *a*. Black argillaceous shale, with compact layers 2 or 3 inches thick	30	
b. Dark, earthy limestone	1	
c. Black shale	2	
	—	33
9. Gray, Stromatopora[1] (?) limestone		8
10. Black argillaceous shale, with variegated shales below, containing more or less arenaceous matter in the form of arenaceo-argillaceous shale and thin layers of sandstone.		

[1] Probably a species of Cryptozoon.

		Feet.	Feet.
	On the slopes light-drab, pea-green, vermilion, chocolate, maroon, and buff-colored shales of various shades alternate		740
11.	Massive stratum of concretionary limestone		10–25
12.	Reddish-brown, sandy shale		25
13. *a.*	Thick-bedded, dark reddish-brown sandstone	70	
b.	Same, thinly bedded	70	
		—	140
	Total thickness of upper division		1700

The last two beds form so strongly marked a horizon in the shaly beds that it is taken as a rough division line in the terrane, the strata beneath containing a different character of limestone that serves to distinguish them.

LOWER DIVISION.

		Feet.	Feet
1.	Brown sandy shales, passing below into chocolate and dark argillaceous shales that alternate with brown and greenish, sandy shales. Near the summit a layer of oölitic iron ore occurs		300
2. *a.*	Alternating sandy and argillaceous shales, with thin belts of limestone from 6 inches to 4 feet in thickness	310	
b.	Stromatopora limestone	4	
c.	Dark shaly limestone	3	
d.	Dark argillaceous shale	6	
e.	Dark-gray shaly limestone in massive layers	2	
		—	325
3.	Chocolate-brown, dull and yellowish-green, sandy and argillaceous shales, with sandstone in narrow bands, and 21 feet of limestone in thin layers near the middle and base of the stratum		625
4. *a.*	The sandstone and sandy shales become less prominent, the argillaceous and calcareous strata replacing them, 54 feet of limestone occurring in 500 feet of strata	500	
b.	Dark clay-shale	4⅓	
c.	Dark shaly limestone	1	
d.	Dark argillaceous shale	4	
e.	Gray limestone, having a tendency to break up into shaly layers; strongly bituminous near the base	5⅔	
f.	Friable, rather coarse, gray to buff sandstone	5	
g.	Compact lead-colored limestone	2	
		——	522

	Feet.	Feet.
5. Black argillaceous shale, with chocolate and greenish, sandy and argillaceous shales beneath, carrying hard layers of sandstone. In a few localities white and pink gypsum occurs in masses a few feet in diameter, or as seams in the upper, black shales		100
6. Three feet of compact, mottled, buff limestone interbedded in 15 feet of brown sandy shale		18
7. *a*. Black and chocolate, sandy and argillaceous shales, with three thin layers of limestone near the base	180	
b. Black and brown argillaceous shale, with interbedded layers of a somewhat friable sandstone	180	
c. Chocolate, green, maroon, drab, argillaceous shales, with thin layers of brownish sandstone interbedded, and, toward the base, sandy shales	360	
d. Brown sandstone, in layers 8 to 18 inches thick, passing below to sandy and argillaceous shales, with layers of buff and chocolate sandstone	55	
e. Drab argillaceous shale, passing down into brown, sandy, ripple-marked shales	55	
		830
8. *a*. Massive band of irregular, thinly bedded limestone, gray and buff except near the chocolate-colored upper stratum. A variety of limestone occurs. *b*. Chocolate-colored, compact layers, with a smooth, partially conchoidal fracture. *c*. Evenly bedded, thin layers, hard, lead-colored. *d*. Thin, shaly, gray layers. *e*. Very irregular and concretionary layers. *f*. Compact, gray, bituminous layers. Total		50
9. Dark argillaceous shale, with a strongly marked band of a deep-maroon color; drab, yellowish-green, and dark or brownish-black shales continue below to a dark-chocolate band that is superjacent to 100 feet of drab and greenish shales. The shales are largely argillaceous, with arenaceous matter scattered through the section as sandy shales, thin-bedded sandstone, and arenaceo-argillaceous shales. In one locality a band of fine-grained gray limestone, 6 inches thick, occurs in the shales 3 inches above the base of the Chuar terrane		450 to 650
Total thickness of lower division		3,420

	Feet.
Total thickness:	
Upper division	1,700
Lower division	3,420
	5,120
Limestone in upper division	138
Limestone in lower division	147
	285

UNKAR TERRANE.

The line of outcrop of the massive magnesian limestone below the base of the Chuar terrane extends south, in the face of the cliffs, to the north side of Unkar Valley. The section was taken from this point south across Unkar Valley and along the walls of the inner canyon of the Grand Canyon to a point south of Vishnu's Temple, where the sandstones and conglomerates rest unconformably upon the sandstones, schists, etc., of the Vishnu terrane and the gneisses, schists, etc., of the Archean. The section is characterized by a great thickness of reddish-brown sandstones.

Section from the Summit downward.

	Feet	Feet
1. *a.* Massive beds of gray to reddish magnesian limestone, passing below into a calciferous sandrock	50–150	
b. Light-gray shaly sandstone	25	
c. Irregular massive beds of yellowish-brown sandstone,	50	
d. Partially cross-bedded, fine-grained, purplish-brown sandstone	50	
e. Reddish-brown sandstone and sandy shales, ripple-marked	200	
		475
2. Lava beds:		
a. Dark-green basaltic rock with a reddish tinge. Breaks into small angular fragments. Upper surface slightly irregular	100	
b. Layers of a reddish-brown sandstone	8–10	
c. Solid, compact lava, of a dark-green and reddish tinge, with a slight tendency to columnar structure	70	
d. A layer of sandstone, 1 foot in thickness, caps a massive flow of dark-green lava, which breaks up and weathers into a fine talus of a lighter green than the rock in place	100	
e. A flow not unlike *d*, and capped by a layer of sandstone 2 feet in thickness	70	

	Feet.	Feet.
A layer of vesicular lava with a thin stratum of sandstone at the summit	10	
g. Solid, compact lava, of a dark-green and reddish tinge, with columnar structure partially developed in the central portion. This band appears to be formed of three flows in quick succession, as no sedimentary material accumulated on the surface of the two lower; 25, 125 and 25 feet; total	175	
h. Reddish-brown sandstone, compact and slightly metamorphosed toward the summit	15	
i. On the weathered surface this flow presents a slope of 25° to 30°, rarely forms a cliff, as do the flows above, and the rocks crumble into a rather light olive-green, coarse sand. Thin beds of reddish-brown sandstone occur in several places, and one, 125 feet from the base, is quite persistent in its horizontal extension. The upper surface of the flow is slightly undulating and more or less nodular	250	
		800
3. Sandstones (upper):		
a. Shaly, vermilion, rather fine-grained sandstones, with intercalated bands of a greenish-gray, followed below by 700 feet of vermilion beds of a uniform character, and massive beds with arenaceous, shaly partings, the massive beds breaking up into shale and sandstone on the talus slopes. Ripple-marks and shrinkage-cracks characterize the upper, shaly beds	1,730	
b. The vermilion sandstones of *a* pass into chocolate-colored sandstones, that for 125 feet down unite in the general slope of the beds above. Below, a cliff is formed of five massive bands of chocolate-colored, slightly micaceous sandstone, separated by shaly sandstone partings of a greenish color below and a chocolate color above	925	
c. Reddish-brown to chocolate, more or less shaly sandstone, 125 feet, underlain by 300 feet of friable sandstone and arenaceous and micaceous shale	425	
d. Irregularly bedded, compact sandstone:		
Curiously twisted and gnarled layers	15	
Massive, grayish layer	10	
Light-gray layer with reddish spots, friable, shaly in places	125	
	150	
		3,230

	Feet.	Feet.
4. Sandstones (lower):		
a. Compact, quartzitic, gray sandrock, 25 feet, with 65 feet of hard, compact sandstone	90	
b. Massive, compact, cliff-forming, brown, buff, and purplish-brown sandstone	1,200	
c. 1. Reddish-brown to vermilion, friable, shaly sandstone 200		
2. Brick-red shaly sandstone 250		
3. Brown, friable, shaly sandstone, ripple-marks and shrinkage-cracks 300		
4. Same in more massive layers, with fine, siliceous conglomerate (10 feet) at the base 80		
	830	
		2,120
5. *a*. Light-gray limestone, with interbedded laminæ of quartzitic shale	8	
b. Brown sandstone, with a bed of siliceous conglomerate, 2 feet	30	
c. Reddish, cherty limestone	10	
d. Reddish-brown limestone	2	
e. Dark reddish-brown slate,	5	
f. Light-gray, compact, shaly limestone	14	
		69
6. Dark, compact, basaltic lava in one massive flow		80
7. Light-gray, compact, shaly limestone with pinkish tinge between the laminæ; it is a little cherty near the base, or with thin, hard, interbedded layers of sandstone		26
8. Siliceous conglomerate, formed largely of pebbles derived from the upturned edges of the pre-Unkar strata, upon which it rests unconformably		30
Total thickness of the Unkar terrane		6,830
Total thickness of the Chuar terrane		5,120
Total thickness of Grand Canyon series		11,950

VISHNU TERRANE.

The strata of the Vishnu terrane on the north side of the Grand Canyon, due south of Vishnu's Temple, consist of micaceous schists and quartzite, with dikes and veins of reddish colored granite cutting across the plicated bedding of the schists, etc. I examined this series at one point only, and do not feel warranted in discussing its general characters. On the south

side of the canyon the strata occupying the same relative position beneath the base of the Unkar terrane have been considered to be of Archean age.

SEDIMENTS AND CONDITIONS OF DEPOSITION.

Over the eroded, upturned beds of the Vishnu terrane a bed of siliceous conglomerate, composed largely of pebbles derived from the beds below, indicates the old sea-beach formed during the period preceding the deepening of the water. In this sea sand and a few beds of calcareous mud accumulated prior to the spreading of a flow of basaltic lava which now forms a massive bed 80 feet in thickness. In the period of quiet following the lava-flow, a few alternating beds of calcareous and arenaceous mud and sand were deposited prior to the deposition of 5350 feet of sandy beds, which now form rather fine-grained, vermilion, chocolate, brown, buff, and parti-colored sandstones. With the close of this epoch of arenaceous deposition the sea-bed and the strata beneath were fissured by crevices which extended down into the Archean, and flow after flow of basaltic lava poured out through these over the sea-bed. In the intervals between the flows the deposition of the sand continued, and we now find, between the massive lava-flows evenly distributed beds of reddish-brown sandstone. With the last of the six principal flows the sea deepened, and a thick deposit of calcareous mud was accumulated, which now forms a magnesian limestone, passing below into a calciferous sandrock, the whole varying from 50 to 150 feet in thickness. This was the closing deposit of the Unkar terrane. Its upper surface shows slight traces of erosion, and, as the sediments of the succeeding Chuar terrane are unlike those of the Unkar, it is probable that the source from which the sediments were derived changed from one that had contributed a vast amount of sand to one that yielded great quantities of argillaceous matter and sand of a still finer character. It is not to be understood that this implies a change of source of sediment, but rather a change of conditions, produced by progressive erosion that lowered a somewhat elevated area

toward a baselevel before the close of the known upper limit of the Chuar terrane.

The lithologic characters of the Unkar terrane are rather uniform in the upper portion, the strata consisting of reddish-brown and greenish sandy shales, and of layers of a medium-grained sandstone, varying from 2 inches to 3 feet in thickness. In the more thickly bedded portion there is a tendency to form cliffs that resemble the Triassic sandstones of the Vermilion Cliffs of southern Utah, and the shaly portions are much like those of the Trias. As a whole the prevailing color is a reddish-brown, much like that of the Carboniferous Lower Aubrey sandstone cliffs in the canyon wall, 2000 feet above. Traces of life are as yet unknown; ripple-marks, fine and coarse mud-cracks, and all the markings of quiet, shallow water and a low shore-line that was frequently exposed to the action of both water and air, are abundant.

The sandstones of the Unkar group are exposed directly in the Grand Canyon, below the mouth of Chuar Valley; and the rocks of the Chuar terrane occur in nearly all of the canyon valleys between the eastern side of the Kiabab plateau and the six great buttes that form the west side of the lower portion of Marble Canyon.

As indicated by the section, the Chuar terrane was formed and calcareous muds, uniformly spread over a relatively level sea-by the deposition of a great series of argillaceous, arenaceous, bed. The strata now succeed one another as fine sandstones, shales and limestones, the lithologic characters resembling those of the Cretaceous, as seen in the cliffs a few miles to the north. In places the limestones and shales may be compared with the Trenton limestone and the Utica shale of the Lower Palæozoic of the East. The parti-colored shales, in one belt 700 feet in thickness, recall the friable Permian clays. In fact, there is no more evidence of metamorphism throughout the 12,000 feet of the Grand Canyon series than there is in the evenly bedded strata of the Permian, Triassic, and Cretaceous groups of the Plateau Province of northern Utah.

Midway of the lower portion of the shales and limestones of the Chuar terrane the presence of a fauna is shown by a minute discinoid or patelloid shell, a small Lingula-like shell (which may be a species of Hyolithes), and a fragment of what appears to be the pleural lobe of a segment of a trilobite belonging to a genus allied to the genus Olenellus, Olenoides or Paradoxides. There is also a Stromatopora-like form that is probably organic.

The paucity of the fauna in both the Unkar and Chuar terranes demands some explanation, for the strata were apparently deposited under conditions most favorable to the development of abundant life. I find in my field-notes a suggestion that the sediments were deposited in a great inclosed basin, or mediterranean sea, and that during the greater part of the period of their deposition no connection existed by which any fauna then existing outside of this sea could obtain ingress.

The sediments of the Unkar and Chuar terranes, as measured, give a total thickness of 11,950 feet. How much more was planed away by the sea in which the next terrane (the Tonto) was deposited was not determined. With the close of the epoch of the Chuar terrane a period of orographic movement ensued, during which the strata of the Vishnu, Unkar, and Chuar terranes were elevated, broken by faults, and more or less flexed. The summit of the series is now found in a knoll on the divide between Nunkoweap and Kwagunt Valleys. It may have been a remnant left by the sea as the latter cut away the Algonkian land, or a hill remaining above the baselevel of erosion that planed away a section of the entire thickness of the pre-Tonto strata. The surface upon which the sandstones of the lower Tonto were deposited was nearly level. Here and there a hard stratum caused ridges to be left in the Tonto sea, and the fragments broken from them are scattered among, and mixed with, the sands of the Tonto.

Of the duration of the interval of erosion between the deposition of the sediments of the Chuar terrane and the first of those of the Tonto, we can only form a conjectural estimate, based on the sections of Cambrian rocks in northwestern and central

Nevada. The stratigraphic position of the sandstone at the base of the Tonto terrane is that of the Middle Cambrian, a horizon equivalent to that of the lower portion of the St. Croix sandstone of Wisconsin and the Secret Canyon shale of the Eureka District of Nevada. The fauna of the Chuar terrane indicates the presence of life, but it is not of value in stratigraphic correlations. It is probable, almost to a certainty, that it is older than the Olenellus fauna of Nevada. If this be true, the interval between the summit beds of the Chuar terrane and the Tonto sandstone is represented, in Nevada and Utah, by a deposition of 3000 or more feet of limestones and many thousand feet of sandstones and siliceous argillites. With the exception of a few traces at the base of the Tonto sandstone, none of detrital sediments resulting from the erosion of the pre-Tonto land area have been discovered.

GEOLOGIC AGE.

The lower portion of the Tonto terrane, the Tonto sandstone, forms the base of the Palæozoic section in the Grand Canyon District. It is massive-bedded and rather coarse in the lower portion, passing above into shaly, fine-grained, fossiliferous sandstones. The presence of a well-marked Middle Cambrian fauna in its upper portion clearly indicates its geologic age. It is only the absence at the base of the sandstone of the Lower Cambrian or Olenellus fauna that prevents us from carrying the recognized Palæozoic section down to include its oldest known fauna. The period of erosion represented by the unconformity between the Tonto sandstone and the Grand Canyon series is considered to more than equal Lower Cambrian time, and to constitute a well-defined boundary between the Palæozoic and pre-Palæozoic formations. In my earlier work, in 1883, I referred the Grand Canyon and Chuar strata to the Cambrian;[1] but upon further study of the Cambrian rocks and their contained faunas, and in view of the extent of the time-break indicated by the noncon-

[1] Am. Jour. Sci., Vol. XXVI., 1883, p. 441.

formity by erosion, this was changed in 1886, and all the pre-Tonto strata were referred to a pre-Cambrian series.[1]

In the scheme of nomenclature adopted by the Geological Survey in 1888, the clastic rocks beneath the Cambrian and superjacent to the Archean were grouped under the term Algonkian — of equivalent rank to Cambrian, Silurian, etc.[2] In this classification the system name — equivalent to Palæozoic, etc. — was not decided upon; but I am strongly in favor of adopting the name "Proterozoic," proposed by Dr. Irving and accepted by Professor C. R. Van Hise.[3] Under this nomenclature the Grand Canyon series will be referred to the Algonkian system of the Proterozoic group.

There may be a difference of opinion among geologists as to the adequacy of the evidence that the Grand Canyon series is pre-Cambrian. This can hardly be the case with those who have studied the questions of orographic movement and subsequent erosion. The long section on the map shows most clearly that the sediments of the Grand Canyon series were elevated, faulted, and more or less flexed prior to the period of erosion that cut away a section of the entire series and not only reduced to a baselevel the land area formed by the latter, but reduced to the same plane the more resistant subjacent rocks of the Vishnu terrane of the Algonkian, and probably the Archean, to the west. The time required for the orographic movement resulting in elevation and for the subsequent erosion would exceed, in my opinion, the period of Lower Cambrian sedimentation. It is not at all improbable that the sediments of Lower Cambrian time in the Great Basin region of Nevada, Utah, etc., were derived from the Algonkian continent to the east, of which the Grand Canyon series of rocks then formed a part.

CORRELATION.

The Grand Canyon series, the Llano series of Texas, and the Algonkian series of the Lake Superior region afford an opportu-

[1] Bull. U. S. Geol. Survey No. 30, 1886, p. 41.

[2] Tenth Ann. Rept. U. S. Geol. Survey (for 1888–89), 1890, p. 66.

[3] Bull. U. S. Geol. Survey No. 86, 1892, p. 493.

nity of comparing the stratigraphic succession of somewhat similar lithologic series of strata, but a definite correlation can not be made until a more reliable factor is obtained than lithologic resemblance of the various formations. It is quite probable that the Grand Canyon series and the Keweenawan series of Lake Superior represent the same time-interval; also that the strata beneath Packsaddle Mountain, in central Texas, are the equivalent of the Chuar terrane of the Grand Canyon; but until palæontologic evidence is secured it may be said that these correlations are little more than possibilities. The Grand Canyon, Llano, and Keweenawan series may be referred to the Algonkian, as that system of rocks includes the strata of sedimentary origin between the Archean complex and the base of the Cambrian; beyond that any correlation on trustworthy data is impossible. Mr. Iddings's examinations of the specimens of eruptive rocks in the Algonkian of the Grand Canyon series show the basal flows of the Unkar terrane to be a true doleritic basalt, and that the dikes and the upper flows, as exposed in Chuar Butte, etc., are basalts differing but little from the basalts of Tertiary age found in Nevada, Utah, and on the plains in the vicinity of the Grand Canyon. This fact prevents any correlation of the lavas with those of other localities, even though basaltic rocks were found to occur in formations referred to the Algonkian. It is evident that until characteristic fossils are found in the various terranes now referred to the Algonkian it will be impossible to make any correlations that will be more than tentative suggestions.

CHARLES D. WALCOTT.

NEW LIGHT ON ISOSTASY.

FACILITIES for the measurement of gravity by means of the pendulum have been greatly improved in recent years. The apparatus devised by Dr. Mendenhall for the Coast Survey not only affords results of high precision but enables an observer traveling from point to point to make at least one measurement each week. During five months of 1894 Mr. G. R. Putnam, of that survey, occupied twenty-six stations, a greater number than has previously been successfully occupied in North America. The measurements have the further advantage that they are homogeneous, being all made by the same observer with the same apparatus; and as it is understood that the work is to be continued, American geologists and geodesists may confidently look forward to such a knowledge of the distribution of mass in the continent as will materially clarify conceptions of the inner earth.

A brief report of Mr. Putnam's results was communicated by Dr. Mendenhall to the National Academy of Science, and printed in the *American Journal of Science* for January. A fuller account of the work and a discussion of the results were presented to the Philosophical Society of Washington by Mr. Putnam, and have recently appeared in the Bulletin of the Society. Under the same cover also are comments by the present writer.[1] While these discussions are merely tentative, and were undertaken primarily for the purpose of indicating the most advantageous directions for future work by the Coast Survey, certain of the inferences drawn are of such importance and so little liable to be overthrown that their presentation to the readers of the JOURNAL seems warranted.

[1] Results of a Transcontinental Series of Gravity Measurements, by GEORGE ROCKWELL PUTNAM; and Notes on the Gravity Determinations reported by Mr. G. R. Putnam, by GROVE KARL GILBERT. Bull. Phil. Soc. Wash. Vol. XIII., pp. 31–75.

The majority of the stations are arranged in a chain from the eastern coast to Salt Lake City. Two stations are on the Pacific Coast and three in Yellowstone Park. In discussing the measurements, I have started with the general postulate that continents and ocean beds are in isostatic equilibrium, and have sought to determine from the local values of gravity the extent to which various geological provinces of the country deviate from perfect isostatic adjustment. Between the Appalachian and Rocky Mountains is a great plain, which has been exempt for a succession of geologic periods from orogenic disturbances, and during that time has had exceptional opportunity for the gradual relief, through viscous flow, degradation and sedimentation, of the strains engendered by gravity in connection with anomalies of density. It seems, therefore, *a priori* probable that this plain is in approximate equilibrium; and, if so, the average attraction on the plain may advantageously be used as a standard of reference in the consideration of other provinces. Eleven of the stations belong to the plain and they are well spaced from east to west. An examination shows the values of gravity at these stations to be notably accordant. When the mean of the eleven measurements is subtracted from the several measurements, the average residual is found to be only $\frac{1}{120000}$ of g, or such a differential acceleration as would be caused by the addition or subtraction of a layer of rock 240 feet thick.

Referring all the measurements to the standard thus obtained, it is found that there is an excess of attraction in all the mountain districts where measurements were made. In the Rocky Mountains of Colorado there are two stations, at Pike's Peak and Gunnison, and the excess of gravity determined at these stations is equivalent to the attraction of a rock layer 2200 feet thick. That is to say, if this mountain belt, 150 miles broad, were pared away to an average depth of 2200 feet, the local gravitation would then correspond to that on the interior plain. Now it also appears, as a generalization from the Hayden contour map of Colorado, that if this same district were leveled by removing the mountain tops and using the material to fill the valleys, it would

be converted into a plateau between 2000 and 2500 feet higher than the adjacent portion of the plain. The conclusion is thus reached that the whole mountain mass above the level of its base is in excess of the requirement for isostatic adjustment; or, in other words, is sustained by the rigidity of the earth. Three stations in Yellowstone Park tell the same story as to the Rocky Mountains of Montana, and single stations on the Wasatch Plateau and the Appalachian Mountains indicate that those uplands are rigidly upheld.

These results tend to show that the earth is able to bear on its surface greater loads than American geologists, myself included, have been disposed to admit. They indicate that unloading and loading through degradation and deposition cannot be the cause of the continued rising of mountain ridges with reference to adjacent valleys, but that, on the contrary, the rising of mountain ridges, or orogenic corrugation, is directly opposed by gravity and is accomplished by independent forces in spite of gravitational resistance.

While the new data thus indicate that the law of isostasy does not obtain in the case of single ridges of the size of a large mountain range, they agree with all other systems of gravity measurements in declaring the isostasy of the greater features of relief. The mode of reducing gravity measurements at different places so as to make them comparable depends on the theoretic conception of terrestrial rigidity, one method being followed when high rigidity is postulated and another when isostasy is postulated. Under the postulate of high rigidity it is assumed that all parts of the crust have the same density; under the postulate of isostasy each vertical element of the crust is assumed to have the same mass, density being inversely related to altitude of the surface. If either of these postulates were absolutely true the measurements, when reduced in accordance with it, would become identical, except for errors of observation; and approximation to such identity is a measure of the degree of approximation of the corresponding postulate to the actual fact. Mr. Putnam and the writer independently applied

this test by reducing series of measurements under each of the two postulates, and our conclusions are of the same tenor. Treating fourteen measurements, he found the results obtained under the postulate of rigidity fifteen times as discordant as the results under the postulate of isostasy; treating twenty-six measurements, I found the ratio as six to one. These measurements pertain to stations distributed among the plateaus that make up the continent, plateaus ranging in general attitude from 100 feet to 8700 feet; and the comparison shows that these plateaus are approximately in isostatic equilibrium.

G. K. GILBERT.

STUDIES FOR STUDENTS.

JAMES D. DANA AS A TEACHER OF GEOLOGY.

To SIT at the feet of Professor Dana and drink from the overflowing fountains of his knowledge, was a privilege which once enjoyed could never be forgotten. One knew not which to admire most, the simplicity and nobility of his character, or the breadth and grasp of his intellect. Yet none could fail to be impressed with the fact that one was the complement of the other. Had he been less keen, thoughtful, impartial, he would have been less admirable as a man. Had he been less sincere, unselfish, truth loving, he would have accomplished less as a scientist.

Unconsciously but irresistibly as he taught geology, he revealed to his students his own character, and all which he revealed made them long to know him more deeply and truly. He imparted to them too, unconsciously I have no doubt, the principles of the successful pursuit of knowledge and the methods by which progress in science is attained which had enabled him to accomplish Herculean tasks in the same direction and to occupy the prominent place which he did among the scientific workers of his time.

Glancing over the notes of his talks which I made during the two years that I was privileged to study under his instruction, I find many aphorisms which he let fall indicating the methods by which his own success in scientific work was attained. Thus, when stating the different theories which had been proposed regarding the mode of formation of coral islands, he expressed a wish that borings might be made so as to learn on what foundations the islands rest, remarking, "When I get at a thing I want to go to the bottom of it and then I am willing to leave

it." The remark reminds one much of the answer given by Lincoln to a question as to how he gained so clear a knowledge of the subjects with which he dealt, when he said: "I cannot rest easy when I am handling a thought till I have bounded it upon the north, upon the south, upon the east and upon the west."

Another maxim which it would be well to keep in mind in these days of easy publication Professor Dana gave utterance to when, in referring to some of the theories which were being advanced at the time to account for the subsidences of the earth's crust, he said: "I think it better to doubt until you know. Too many people assert and then let others doubt."

The same judicial poise was exhibited in his readiness to change his former opinions when he became convinced that the evidence was sufficient to warrant it. Absolute candor and desire to support only the truth as he saw the truth were among his principal characteristics, and he sought constantly to impress upon his students their importance as factors of success in the pursuit of knowledge.

Thus in studying the Cambrian era, which the labors of Walcott and others at that time had shown to be of far greater extent and importance than had previously been supposed, his students were told to regard it as of equal importance with the Lower Silurian, though in his text-book it was one of the subdivisions of the latter, and his remark at the time was: "I have found it best to be always afloat in regard to opinions on geology."

So too in accepting as divisions of independent continental progress, the Eastern Border, Eastern Continental, Interior Continental, Western Continental and Western Border regions, a classification which differed from that which he had previously made, he said: "I always like to change when I can make a change for the better."

In adopting views which had been originated by others, he never sought to assume from them any credit to himself, but freely gave honor to whom honor was due. This was well illustrated in his espousal of Darwin's theory of the formation of

coral islands. It was a subject to which before the publication of Darwin's views he had himself given much thought, without arriving in his own mind at any satisfactory hypothesis. "As soon as Darwin published his theory, however," said he, "I saw at once that it solved the difficulties of the case," and though he did much to expand and verify it, he never claimed it in any degree as his own. His change of opinion regarding the theory of evolution is likewise well known, and he never hesitated to mention it in his lectures upon the subject.

Upon those, however, who sought to gain scientific repute by any other means than a careful and unbiased study of facts, his strictures were severe. One geologist of some prominence he described as "a man of wonderful resources, because he had only to go to his own brain for facts," and his students were often warned against accepting any of such an observer's conclusions

Woe likewise to the student who sought to conceal the bubble of his ignorance with a thin varnish of words. The bubble would be pricked with a celerity and suddenness that left no desire for a repetition of the experiment.

No man, however, was ever more ready, even eager, to assist those who wanted to obtain knowledge. While he had no time to waste on those who studied geology only as a matter of form, his resources were freely at the disposal of any who displayed intelligent interest in the subject.

One way in which he evinced this was by the long walks which he was wont to take with his students about New Haven, or other trips to places more distant. Though these were over the same ground year after year, he never seemed to weary of the journey so long as his students showed any desire to be instructed by what they saw. Even to the very last of his life these trips were continued, the teacher of nearly fourscore years traveling over rocky steeps and through brambly thickets with all the ease and sprightliness of youth and at a pace which his younger followers found difficult to imitate. The number and variety of illustrations of geological principles which he could point out in such walks of a few hours were indeed remarkable,

and taught his students that they need not go to distant parts of the earth to make geological observations, for they could find material sufficient for study at their own door. The trap ridges, kettle holes and bowlder trains of the vicinity of New Haven have thus become of classic interest, not because they presented any unusual features, but because Professor Dana resided near them, studied them, and gave to the world the results of his observations.

No operation that was carried on within the range of his observation, the details of which could add to the sum of geological knowledge or help solve any of its problems, seemed to escape his notice. Every railroad cut, every survey, every excavation and every boring he carefully watched and gained from them facts which helped him interpret the past history of the earth.

The bricks which were burned in the Quinnipiac kilns he had analyzed in order to learn why they fused so easily, and gained thereby important information regarding the source of the clay. By the dolomitic blocks of the State House he illustrated to his classes the principles of the disintegration of limestone, and by the granite pillars of the Peabody Museum the expansion of stone by heat. From watching the drying of a drop of milk on a stone floor he derived an explanation of the forms produced by concretionary consolidation, and by experimenting with varieties of sand dropped about an upright darning needle established the principles governing the angle of rest for falling detritus.

His ability to retain in his mind various phases of geological evidence, and develop them as time progressed, was likewise remarkable. Thus, in 1889, in his teaching he laid much more stress on the influence of the Cincinnati uplift in determining the character of the rocks of the interior of the continent than he had previously done in his Manual, for he said he had never so fully realized its importance as he had that year.

Nor were his students compelled to receive obsolete theories or time-worn illustrations because he had held or used them

in the past. On the contrary they were kept informed of the newest discoveries and latest phases of geological thought and urged to judge for themselves of their importance and bearing upon previously attested principles. With all the varied lines of thought and discovery he kept in closest touch, and seemed equally appreciative of their value, whether they related to the eruptions of Kilauea, the Algonkian formation, Mesozoic mammals, the causes of oscillation of the earth's surface, or what not. Of this progressiveness and appreciation of all additions to the sum of geological knowledge his newly published Manual gives sufficient evidence.

The quality in an investigator which, other things being equal, he seemed to esteem most highly, was that of *carefulness*. How often were his students advised to trust or to doubt the statements of an author according as he was or was not, in the opinion of Professor Dana a *careful* man. With hasty and ill-considered conclusions or elaborate theories built from meager observations he had no patience, but to opinions which he believed had been derived from a careful and thorough study of facts, he was ever ready to give the fullest consideration, however much they might be opposed to his previous conclusions. "More," he said, "could be learned by studying unconformities than conformities," and this he believed to be as true of unconformable opinions as of heterogeneous strata.

The awakening in his mind of the interest in science which became the ruling passion of his life, and led to his signal achievements for its advance, Professor Dana used to ascribe largely to two causes, one that of having spent much of his early life in the country, the other, his first teacher. In connection with the first he used to deplore the lack of development of the faculties of observation and the ignorance of nature consequent upon life in the city and placed a high estimate upon the education unconsciously gained by an association with the beings and phenomena of the natural world. As an illustration of this the author recalls an occasion when having passed in vain nearly around the class for a statement of the differences between a moss and a phenog-

amous plant, Professor Dana turned to one of the few remaining who had not confessed their ignorance, with the remark, "You are from the country, you ought to know." And he did.

Professor Dana's first teacher was an ardent student of nature who was wont to go with his pupils on long tramps for the purpose of collecting minerals, plants and insects, and aroused in them much of his own eagerness for the pursuit of knowledge. It is therefore but just that some of the fame of his distinguished pupil should be attributed to him. One incident which Professor Dana used to relate to illustrate his teacher's fervor as a collector was that when on one occasion his little party had gathered at a remote place more mineral specimens than they could carry in their hands, the master, in preference to leaving any behind, improvised a bag from a pair of trousers and thus bore them safely to their destination.

To rehearse at this time the principles of geology which Professor Dana taught, or to state the opinions which he gave to his classes upon mooted geological questions of the day, would be quite superfluous, since they have been sufficiently expressed in his recently published Manual, a work fortunately completed just before his death and which came, as another has said, as "the worthy consummation of a long life of exceptional earnestness and success as author, investigator, editor and teacher."

But lest, in contemplating the splendor of his principal achievements, the sidelights which revealed the man and his methods should pass unheeded, it has seemed to me desirable to fix and record them for the encouragement and guidance of those who may desire, however humbly, to follow in his footsteps. There can be no doubt that with him the tenth muse was work, in whose wake the other nine followed, yet the union to this capacity for almost unlimited labor, of breadth of mental vision, calmness of judgment, fertility of resources, strict integrity and loftiness of purpose, did much to render it effective, and enable him to accomplish more than perhaps any other man of his time for the advancement of American geology.

OLIVER C. FARRINGTON.

Editorial.

In the death of Professor James D. Dana, American geology loses its most eminent representative. With due recognition of the preëminence of others in their chosen lines, no one has stood before the scientific world for the last three decades so widely recognized as the foremost general geologist of our hemisphere as Professor Dana. The period of his activity has stretched over a full half century. From the time of the publication of his great work on the results of the Wilkes Exploring Expedition, his eminent ability has been recognized, and the appearance of his manuals of geology and mineralogy, which soon followed this, gave him a position of unequaled influence among the teachers and students of those sciences in this country. Upon these works his reputation chiefly rests. Owing to the delicacy of his health his field work was limited, and subsequent to the Wilkes Expedition, which gave him so comprehensive a familiarity with the great features of the earth, his personal field investigations were chiefly confined to the region adjacent to his home. His main work was that of compilation, interpretation and organization, and in this delicate field he showed great judgment and discretion. As we hope to publish a full and appropriate memoir at an early date, and as we give in this number a sketch of his characteristics as a teacher, prepared by an admiring pupil, it would be unfitting here to attempt a full analysis of his conspicuous services or his abilities. He preserved his activity to the end of his life, fourscore years and ten and two, in a remarkable degree. The revision of his Manual of Geology, but just issued from the press, is a conspicuous illustration of this. But his activity did not rest even here, as it might very fittingly have done after so arduous a task. In a

letter to Mr. Leverett, only two days before his death, he added to the immediate purpose of his communication a discussion of the mode of deposition of the loess. By permission this is here added because of its interest as one of the latest, possibly indeed the very last, scientific discussion which he committed to writing. C.

[*Extract from a letter written by Professor James D. Dana to Mr. Frank Leverett, dated April 12, 1895, but two days before his death.*]

"With regard to the eolian work along valley plains, I think great caution is necessary because eolian work is of a fitful kind. The more powerful winds blow in gusts, or rather a succession of them, and each of the gusts is of rather narrow limit; and in each gust great velocity is succeeded by a decline in which the depositions vary accordingly as to coarse and fine and limit. Making loess — unstratified — by the winds would require a steady breeze sufficient to move the light earth or sand long in a common direction, but too near unvarying in force or velocity to produce alternations from coarse to fine. It is an even kind of work that winds are not often fit for. They heap up at the slightest provocation, strike the ground and glance off when of greatest force. It takes something of a breeze to even start the dust of a road, because the dust is 2000 times heavier than the air and the air near the ground slips over the surface readily without disturbing it. Excuse me for thus discoursing on wind work.

"Do you know what is the size of the largest pebbles taken up by a storm wind from a level surface and carried, as it carries sand, for a few yards? The houses in the track of some of the great western gales must have windows sometimes broken in this way; and perhaps their owners, if reliable, could give some facts worth knowing."

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An additional loss has been suffered by geology in the recent passing of Professor Henry B. Nason. While primarily a chemist and mineralogist, Professor Nason was an earnest and conscientious student and teacher of geological phenomena. An exceptionally wide traveler, his personal familiarity with American and foreign deposits was unusually extensive, and gave to his instruction breadth and balance. His primary geological interest lay in the field of volcanic phenomena. Although an

author and an editor of chemical and mineralogical works, his great modesty withheld him from publication in geological lines, so that it was chiefly as a teacher that his wide observations were made serviceable. The writer owes to Professor Nason, as his first teacher in geology, a debt of gratitude for the initial awakening of what has become the dominant interest of his life. Professor Nason was one of the founders of the American Geological Society. C.

PUBLICATIONS.

Die Entstehung der Blei-, Zink- und Eisenerzlagerstätten in Oberschlesien. Eine Besprechung von H. HÖFER. Separatabdruck aus der "Oesterreichischen Zeitschrift für Berg- und Hüttenwesen." XLI. Jahrgang, 1893.

This very interesting paper is itself a review of three publications by Küntzel, Fr. Bernhardi and Rich. Althans, which were presented at the Breslau meeting of the Verein der Allegemeinen Deutschen Bergmanstage, all treating of the ore deposits of Upper Silesia.

These important deposits, from which have been derived by far the greater part of Germany's zinc output, are briefly and excellently described by Althans, as follows:

"The ores of the Upper Silesian Muschelkalk[1] are principally galena, zinc-blende, smithsonite, marcasite and limonite. These occur in bed-like deposits in the dolomite of the Lower Muschelkalk, the beds being usually more or less connected. Generally two beds, or deposits at two different horizons, can be distinguished: one immediately above what is known as the Sohlenstein and separated from it only by a bed of slate known as Vitriolletten, or by a layer of dolomite which is seldom over one or two meters thick; the other in the mass of the dolomite at a very variable distance above the first. The upper one is of much more irregular distribution than the lower; in the Trockenberg basin it is indeed almost entirely absent. Both are in part purely lead-bearing, but they are then rarely more than a meter thick, and at the same time are much interrupted; in part they are predominantly zinc-bearing, and in this case they are much thicker and occur more frequently as continuous beds. The lead-bearing beds belong principally to the Trockenberg basin, the zinc-bearing almost exclusively to Beuthen. In both, the whole thickness is not of compact ore, but this is almost always intermixed with dolomite, which, in fact, generally makes up the mass of the ore body. Where the deposits are zinc-bearing, the lower portion consists mostly of zinc-

[1] Lower Triassic.

blende, together with sulphide of iron and galena; the upper part consists almost exclusively of the so-called red calamine, that is, a ferruginous, zinciferous dolomite, with some galena. The dolomite, which occurs both below and above as well as *in* the lower blende-bearing beds, has almost always the original bluish gray color, whereas in proximity to the upper portion it is more or less decomposed.

"Towards the outcrop the deposits of the two principal horizons unite and form a body that in places is as much as twenty meters thick. Here it consists principally of the red calamine with galena. The ore often extends also down into the Sohlenstein, along crevices and pipes, in which case it is more clayey. In the extremities of these openings the iron contents also disappear, so that the ore passes into a white calamine (a dolomite rich in $ZnCo_3$)."

The three publications referred to include maps and descriptions of the ore deposits, and discussions of their genesis. Höfer considers principally the last, analyzing and comparing the different hypotheses in a very interesting manner.

Thus, Bernhardi maintains the hypothesis that, after the deposition of the basal Sohlenstein formations, rich solutions of zinc, lead and iron salts were introduced into the Triassic sea, from which they were precipitated either by CO_2 or H_2S, which were evolved in abundance from the then recently formed and underlying coal beds. The ore deposition was most abundant where these gases were generated in greatest quantities.

Bernhardi bases his conclusions upon the fact that the zinc deposits are developed in the Muschelkalk only where there are well-developed coal formations beneath, and especially where such outcropped in the floor of the Triassic sea. Höfer calls attention to the deposits of Tarnowitz as an exception, and remarks, very truly, that this condition is equally favorable to the hypothesis of infiltration as to that of original deposition.

In further support, Bernhardi cites the facts that there are no evidences in the underlying Coal Measures or in the Sohlenstein that the ores have come from below, and, further, that faults of the Coal Measures either do not extend into the Muschelkalk or have very little throw there. These facts Höfer classes also as equally favoring infiltration.

Against the latter hypothesis Bernhardi instances the stratum like form of the ore deposit, and the unaltered or unoxidized condition of the dolomite which is associated with the sulphides. Höfer does not

think these objections valid. The stratified form, he argues, might readily be due to the impermeability of the Sohlenstein, which would cause the waters to flow along the contact between it and the permeable dolomite above, while the carbonaceous Vitriolletten bed would precipitate the ores. The unoxidized condition of the dolomites and clays does not mean necessarily that no waters traversed them, but merely that these waters had no air or free acids in solution. Such could well have been exhausted, says Höfer, in oxidizing the sulphides of the higher strata, before transporting them to the present ore horizons. Further, Höfer reasons, on the hypothesis of sedimentation, beds of dolomite and limestone would have been deposited in alternate layers in the ore body, as they were before and after. Not only is this not the case, but Bernhardi describes a brecciated structure which sometimes characterizes the greater part of the deposit, where blocks of dolomite are cemented by the ore. This condition, as well as the presence of vertical and other ore-bearing crevices in the dolomite, is incompatible with a sedimentary origin of the ores. Hence, Höfer thinks, this hypothesis must be abandoned.

Althans, in discussing the source of the ores, shows that Krug von Nidda's explanation, that the solutions came from below through pipes or chimneys, will not hold, because when such pipes have been followed into the Sohlenstein they have always come to an end.

Against Dr. Kostmann's hypothesis, that the solutions came from the interior through crevices or fissures, are the facts that the fissures of the Coal Measures almost never extend into the Triassic; that there are no deposits in the underlying bituminous Sohlenstein, and that no such source of supply has been encountered or is indicated in mining operations. Höfer, therefore, discards also the hypothesis of ascending solutions.

The remaining alternatives are defined as follows:

1. The metals were originally diffused in the sedimentary complex overlying the Sohlenstein and subsequently leached out and deposited at the present ore horizon.

2. The ore deposits were originally concentrated sediments which acquired their present forms by subsequent rearrangements and changes.

The first of these hypotheses was advanced long ago by Carnall, and was accepted by Websky, Runge, Römer and others. These older authors referred to the dolomite alone as the source of the ore, and

Carnall estimates that 0.0008 per cent. of galena in this rock would suffice to supply the ore deposits. Such a minute quantity, it is argued, might well escape detection in the analysis of limestone; but, Höfer remarks, even the absence of the metals in the dolomites at present is no objection, since they have been already leached out. Althans thinks it highly probable that not only the dolomite but also the Upper Muschelkalk and Keuper beds, and even others lying higher contain diffused metals and were sources of supply to the ore deposits. But Höfer thinks this improbable because of impervious beds in the Keuper and also at the base of the Upper Muschelkalk.

In conclusion, Höfer sees no unanswerable objection to the explanation of the origin of the ores by descension and infiltration.

The second alternative hypothesis was advanced by an anonymous G. W. in 1883. It resembles somewhat Chamberlin's hypothesis applied to the Wisconsin ores, though the causes and conditions of original concentration are somewhat different and the degree of concentration somewhat greater than Chamberlin requires.

Höfer evidently favors this explanation, without distinctly saying so, but confines himself to the conservative statement that it deserves more consideration. Against Althan's objection that such enormous metalliferous deposits could not be precipitated directly from sea water, he refers to the iron deposits of the southern shore of the Oberen Sea and to the Rammelsberg copper deposits. The sea water of past ages can well have had, he argues, higher metalliferous contents, seeing that so much has now been extracted to form our ore bodies. The abundance of carbonaceous matter at the beginning of the dolomite formation would cause an excessive if not entire precipitation of the metal contents of the sea water. As the bituminous Vitriolletten became covered this would diminish. The dolomite being throughout somewhat bituminous a constant separation of metals in small quantities probably continued, sufficient to impregnate the rock and to account for the scattered occurrences of ore found in it. The alteration of the original deposits to their present forms must have taken place later, after oxidizing influences began to act. Höfer considers this hypothesis simpler, in that it does away with the necessity for the transportation by infiltration of metalliferous salts, and the whole open question of their solubilities is eliminated.

After briefly reviewing similar ore deposits of other parts of Europe, our author concludes that they cannot be better explained than on the

hypothesis that the strata were ore-bearing at the time of their formation, and that the metals were derived from sea water.

This paper is well worthy of study by American geologists. Whether the explanations are applicable to any of the similar ore deposits of this country or not, the discussions are full of suggestion, and are instructive examples of conservative reasoning.

ARTHUR WINSLOW.

ST. LOUIS, March 13, 1895.

Fragments of Earth Lore. By JAMES GEIKIE, D.C.L., LL.D., F.R.S., *etc.* 428 pp, 6 plates. John Bartholomew & Co., Edinburgh.

This volume contains a series of essays and addresses, most of which have been published elsewhere. Many of them have appeared in the Scottish Geological Magazine, while some have appeared in other publications which are less accessible to American readers. The scope of the volume is indicated by the following titles which serve as the headings of as many chapters: Geology and Geography; The Physical Features of Scotland: Mountains, their Origin, Growth, and Decay; The Cheviot Hills; The Long Island, or outer Hebrides; The Ice Age in Europe and North America; The Intercrossing of Erratics in Glacial Deposits; Recent Researches in the Glacial Geology of the Continent; Glacial Period and the Earth-movement Hypothesis; The Glacial Succession in Europe; The Geographical Evolution of Europe; The Evolution of Climate; The Scientific Results of Dr. Nansen's Expedition; The Geographical Development of Coast Lines.

As will be seen by the titles, the several chapters have no intimate relation to each other, though most of them deal with geographic phases of geology. Each chapter is complete in itself. While some of the essays deal with phenomena which are local, all of them deal with principles which are more or less general in their nature, and many of them deal with phenomena which are of universal interest. The subjects are treated in a way which is popular without being unscientific. A service is rendered to students and teachers of geology in collecting and presenting the essays in a single volume, which should find a place in every geological and geographical library. The untechnical language of the essays will make the book available for

the use of many who are not specialists in the sciences to which the essays especially relate. The maps are very valuable, but the volume is otherwise but slightly illustrated.

R. D. S.

POST-GLACIAL SUBMERGENCE IN THE REGION OF THE GREAT LAKES.

Raised Beaches of Lake Michigan. FRANK LEVERETT. (1889) Wisconsin Academy of Science, Vol. VII., 83–87.

Abandoned Shore-lines of Green Bay. By F. B. TAYLOR. American Geologist, Vol. XIII., May, 1894.

Abandoned Shore-lines of the South Coast of Lake Superior. By F. B. TAYLOR. American Geologist, Vol. XIII., June, 1894.

Coastal Topography of the North Side of Lake Superior. By A. C. LAWSON. (1893) Twentieth Annual Report of the Geological and Natural History Survey of Minnesota for 1891, pp. 181–289.

Ancient Strait at Nipissing. By F. B. TAYLOR. Bulletin Geological Society of America, Vol. V., 1893.

Limit of Post-Glacial Submergence in the Highlands East of Georgian Bay. By F. B. TAYLOR. American Geologist, Vol. XIV., November, 1894.

The Duration of Niagara Falls. By J. W. SPENCER. American Journal of Science, 3d Ser., Vol. 48, p. 455, December, 1894.

The investigations by various observers within the last five or six years have added greatly to our knowledge of the Pleistocene history of the Great Lake region. Following is a brief summary of the results of these observations.[1] Mr. Leverett's paper deals with the raised beaches and sea cliffs around the head of Lake Michigan. Three distinct beaches are recognized which are continuous and traceable for a long distance. These are designated the Upper, Middle and Lower raised beaches. Between Waukegan and Winnetka, Illinois, the lake is farther west than when the beaches were formed and is gradually encroaching upon the till-covered country beyond. At Winnetka the base of a sea cliff twenty feet high lies sixty feet above the level of Lake Michigan (641). Southward the cliff becomes continuous with the

[1] For convenience the elevations referring to sea level are placed in parenthesis.

upper beach of gravel and sand which maintains an altitude of sixty feet to within a short distance of the Chicago River where it decreases to a height of forty feet (621). At La Grange there is another sea cliff with its base forty-six feet above the lake. At the time this beach was formed, the lake had an outlet down the Des Plaines valley at Summit, and another entered the same valley from the east at The Sag, about three miles below. The depth of water passing through this outlet at the time this higher beach was formed was forty or fifty feet. East from Summit, the beach ridge stands at sixty-five feet near Homewood (646), fifty-five feet near Glenwood, and eastward to Dyer, in Indiana (636).

The middle beach is about twenty-five feet below the upper, and the lower beach ten feet below this.

Beginning at Sheboygan, Wisconsin, Mr. Taylor's observations extend northward along the western shore of Lake Michigan. The greatest submergence noted is not considered by this author to be represented by any of the terraces described by Mr. Leverett. Evidence of submergence was found at Kewaunee in a low terrace fifteen to twenty feet above the lake (601). Northward the corresponding beach lines rise gradually, and at Menominee on the west coast of Green Bay, there is a well marked beach ridge fifty feet above the lake (631). On the north shore of Green Bay several beaches are distinguished, the highest being 135 feet above the lake (716). Northward from Brampton the general appearance of submergence seemed to extend some distance north of Lothrop, which is 460 feet above the lake (1041), but no shore line was seen. At Marquette a strongly developed shore was found at 590 feet above Lake Superior or 1191 feet above sea level. There is thus seen to be a depression in the beach lines in the vicinity of Kewaunee, north of which the rise is about eight inches per mile for seventy-three miles, while the succeeding sixty-three miles have a rise of from two feet two inches to two feet four inches per mile. Compared with the eastern shore of the lake, the beach on the west appears to be about twenty to thirty feet lower in the same latitude.

Along the south shore of Lake Superior the line of submergence ranges from 572 feet above Lake Superior at Duluth (1173) to 630 feet at Marquette (1231), decreasing from this point eastward to 452 feet at Sault Ste. Marie (1053) (Lawson). The suggestion is made that during the great submergence the Superior basin connected with Hudson Bay by one or more straits.

According to Lawson a very evident relationship exists between the topography of the north side of Lake Superior and the geological structure of the region. From Duluth eastward the Keweenian, Animikie and Archean constitute successive geological provinces marked by characteristic topography. The Potsdam is represented to a limited extent in the vicinity of Sault Ste. Marie, and is of especial interest as forming the dam in St. Mary's River which holds the waters of the lake at their present level. The beaches, bars, spits, deltas and wave-built terraces are described in detail. The highest mark of submergence was found at Mt. Josephine at a height of 607 feet above the lake (1208), while the number of strands recognized in at least two localities was thirty-one, ranging up to a height of 534 feet (1135). This was the level of the highest strand noted at Duluth, while at Sault Ste. Marie the highest was 413 feet (1014). It is evident, however, that owing to the difficulties attending observation the record of the higher strands is very incomplete. On the supposition of the lowering of a lake barrier to the southeast it is evident that the outlet of the vast sheet of water represented by these strands shifted from time to time in consequence of continental warping. The evidence of an outlet into Hudson Bay referred to by Taylor is given and others noted.

Observations at Mackinaw Island had shown the existence of a shore line 205 feet above the lake (786) which was correlated with the Algonquin beach of Spencer, and the belief was entertained that an old outlet of Lake Warren would be found at Nipissing. Later investigation, the details of which are given in the fifth paper, corroborated this conclusion. This ancient strait, as defined by the two highest shore lines, was about thirty-two miles wide where observed, narrowing eastward to about twenty-five miles. Its depth over the low pass between Lake Nipissing and Trout Lake must have been nearly 500 feet.

The last paper by Mr. Taylor records the results of observations between Lakes Simcoe and Nipissing, where the altitudes of the highest beaches observed range from 780 feet above sea level at Barrie to 1140 at North Bay on the east shore of the latter lake. The identity of the upper beach of the Nipissing region with the Iroquois or Algonquin beach of the Ontario basin is reaffirmed.

The eastward rise of the Algonquin beach noted by Dr. Spencer in the region west of Lake Simcoe was corroborated. Great silt-beds were found showing singular alternations of clay and silt in laminæ often not more than one-half inch in thickness. The evidence is con-

sidered strongly against the theory of glacial dams, and favors the inference that the submergence was an invasion of the sea through a strait over Lake Nipissing.

Previous estimates of the age of Niagara Falls are given in the paper by Dr. Spencer, and attention is called to the error introduced into the later computations by neglecting to take into account the changing episodes of the river. It is noted that previous writers have overlooked the presence of an ancient drainage of Lake Erie about forty miles west of the Niagara. Moreover, the assumption often made that the old course of this river passed through the whirlpool ravine is shown to be erroneous.

There was no preglacial Niagara River, and the present channel has been cut almost entirely in limestone. The Horseshoe falls during forty-eight years has shown a mean rate of recession of 4.175 feet per year. The American falls, however, has retreated but 0.64 feet per year during this period. Four different episodes are recognized. The first represents the recession of the falls from the escarpment to the level of the Iroquois beach, which is computed to have occupied 17,200 years. The second stage began with the lowering of the water at the end of the first and the recession of the falls to the vicinity of the whirlpool—a period of about 10,000 years it is thought. The third stage was the time passed at the whirlpool rapids—computed to be 800 years. The fourth episode is characterized by the rising of the waters in the Ontario basin. In the first part of this episode the river cut its way through a ridge (Johnson's) of limestones, following which comes the modern stage of the falls. The duration of this epoch is placed at 3000 years, making a total of 31,000 years, or, allowing 1000 years for the time before the advent of the falls, the age of the river is 32,000 years.

In the deformatory elevation of the district, Johnson's ridge was raised twenty-four feet above the Chicago divide, causing an overflow in this direction which threatened to end the falls when the cut through the ridge was effected. On this basis the drainage of Lake Michigan by way of the Des Plaines ended about 1500 years ago. At the present rate of terrestrial deformation, the falls will come to an end in about 5000 years, by the turning of the waters into the Mississippi. The conclusions of the paper are based on a long series of observations which have been given in detail in a number of papers, a list of which accompanies the present article. C. H. G.

Geological Survey of Ohio ; Geology, Vol. VII., by PROFESSOR EDWARD ORTON, State Geologist, 1893.

This volume although entitled "Geology" is of a more or less composite character. It is divided into two parts, the first treating of Economic Geology, and the second treating of the Archæology, Botany and Palæontology of the State of Ohio. These various subjects are treated by various authors. Part I. of the volume is divided into four chapters : Chapter I. on the Geological Scale and Geological Structure of Ohio ; Chapter II. on the Clays of Ohio, their Origin, Composition and Varieties ; Chapter III. on the Clay Working Industries of Ohio ; and Chapter IV. on the Coal Fields of Ohio.

Chapter I., by Professor Orton, gives a general summary of the various geological formations comprised in the state, with special reference to those carrying products of economic value. The Geological structure of the state is also briefly but clearly described, including the Cincinnati axis, the Appalachian folds, and various other structural features of the state.

Chapter II., by Professor Orton, discusses the origin, composition, and nature of clays in general, and describes the different kinds found in Ohio. The lowest formation in the state known to have been worked for clay is the Medina shale in the Upper Silurian, and from this up to the Coal Measures numerous other formations contain clays of commercial value. The most important deposits are in the Carboniferous rocks, and especially in the coal mining districts where they are often directly associated with coal. By far the most extensively used deposit in the state is what is known as the Kittanning clay in the Carboniferous series.

Chapter III., by Edward Orton, Jr., is a very exhaustive and an exceedingly valuable article on the clay industries of Ohio. He shows that the manufacture of clay wares in Ohio has increased immensely in the last ten years, so that it is now second only to coal mining among the industries developing the natural resources of the state. The nature and origin of clays and their chemical and physical properties as related to their commercial uses, and the methods of testing them, are treated in detail. The present prosperous condition of the clay industry of the state is shown to be dependent largely upon the manufacture of pottery, paving materials, pipes, refractory materials and building materials. Each one of these classes of

materials, and their manufacture in Ohio, is then discussed. The newest of these industries, and the one which has shown the most marked increase, is the manufacture of paving materials which, in the form of vitrified bricks, have been shown to have remarkable endurance even under heavy traffic. The industry has increased at a wonderful rate during the past five years.

This article presents the subject in a clear and concise manner. It shows a thorough insight into the clay industry and is sure to be of much value to those interested in the development of clay deposits, not only in Ohio but elsewhere.

Chapter IV., by Professor Edward Orton, is a thorough discussion of the coal resources of the state, and a résumé of the work which has been done by the survey in previous years in this field. The author first discusses the origin of coal in general, and shows the gradual development of the peat theory from the time it was originally suggested by Leo Lesquereux until the present. The Ohio coal is shown to have been formed in long narrow belts following the line of an old bay of the Carboniferous ocean, which had for its western limit and shore line the gradually rising Cincinnati axis. The coal, therefore, is to be expected to occur on lines running parallel to this old shore and gradually to disappear in the other direction, *i. e.*, at right angles to the shore.

The coal-bearing rocks underlie 10,000 square miles in eastern Ohio, but coal does not occur throughout all of this area. There are fifteen or eighteen seams of coal of economic value, ten of which are of much importance. In the series of rocks carrying the coal, there are twelve beds of limestone, some of marine and some of brackish water origin, which are often more or less replaced by iron.

The value of coal and the wasteful methods of mining and using it, practiced in Ohio and elsewhere, are severely criticised. It is shown that Ohio has probably, according to two different calculations, 12,000,000,000 and 20,000,000,000 tons respectively of available coal left, and that if the rate of consumption should advance as it has done in recent years until it reached a maximum of 100,000,000 tons yearly, the coal of the state would last, according to two different calculations only one hundred and two hundred years, respectively, while if the rate of increase ceased at 25,000,000 tons yearly, the coal would last five hundred and eight hundred years respectively,

The nature and distribution of the different coal seams are dis-

cussed in full, and the volume is accompanied with ten maps, one showing the general distribution of coal in the state and the other nine showing its distribution over local areas. These maps outline the course of the outcrops of the coal and the probable area underlaid by different seams, so that they will be of very great value to all those interested in the present or prospective development of coal fields. Probably no one feature developed by the Ohio Survey in its many years of existence will be of more economic value than these maps.

The important oil and gas resources of the state are not treated in full, but are briefly discussed in the preface. The most important recent developments in the oil industry are the increased number of discoveries in the Trenton limestone, and the increased production from that source. This formation is now the leading source of illuminating oil in the United States.

The supply of natural gas has greatly decreased in the last few years. In 1890 Professor Orton made the prediction that unless the reckless waste of gas was restrained, the supply would soon be exhausted. At that time the use of gas was at its height and was adding immensely to the welfare of the state, not only in supplying a cheap, clean and convenient fuel to the people of the state, but in attracting new manufacturing industries. The predictions of Professor Orton, therefore, were criticised as entirely unwarranted; but recent developments have verified the justice of his warnings. Most of the gas wells show signs of diminished capacity; many have been completely exhausted, and various industries started, or for some years run on gas, have now had to resort to coal.

The chapter on the Archæology of Ohio is by Mr. Gerard Fowke of the Ethnological Bureau of the Smithsonian Institution. It treats the subject in much detail, under the headings of Palæozoic Man; Enclosures, Roadways and Mounds; The Mound Builders; Indians; Relics.

The chapter on botany, by Professor W. A. Kellerman and W. C. Werner, is a complete list of Ohio plants. It combines not only the information given in previous lists, but also many new determinations, making it much more complete than any other previously published and of especial value to those interested in Ohio botany.

Professor Orton states in the preface of the volume that it is the last official publication of the kind that he expects to prepare. This news will be received with much regret by all geologists, and especially by those who have watched Professor Orton's excellent work carried

on in the face of many disadvantages, not the least among which were small appropriations, ever since he assumed control of the Ohio Geological Survey in 1884. A comparison of the state of knowledge on Ohio geology at that time and at the present speaks for itself as to the efficiency of the work he has carried on. In previous years, under the direction of Professor Newberry, many of the most important features of the geology of the state were made known, but many were left undisclosed, and it is to Professor Orton that we owe our knowledge of these, as well as the systematic presentation of many former discoveries. Not only has Professor Orton brought out many facts of very great geological importance, but he has also developed the economic side of the question in an admirable manner, thus rendering the survey useful not only to the scientist, but also to the vast mass of the citizens of the state for whose good the appropriations for a geological survey were especially intended. The collection of purely scientific data in a region is necessarily the first step in the work of a geological survey, and is of great value to all geologists; but he who stops his work here does not fulfill the objects for which appropriations for geological surveys are usually made. The average citizen is not a geologist; purely geological discussions are unintelligible to him. He can draw no deductions from them, and the duty of one in charge of a geological survey is to draw economic deductions from his scientific studies, and publish them in a form which can be understood by the mass of the people of the community taxed to carry on such work. Many who have charge of surveys fail to do this, either because they do not realize its importance, or because they have a weak-minded idea that to make economic publications is unworthy of them.

Professor Orton has in an admirable way given to the people of Ohio all the economic results possible. He has in his various publications first presented his purely geological data, and has then discussed in detail all conclusions therefrom which could be of material benefit to the people of the state. He has thus accomplished the highest objects of a geological survey, and the thanks of the people of Ohio and of the country at large are due him. Most prominent among his works on the economic resources of the state are the treatises on petroleum and natural gas, embodied in Preliminary Reports of Progress, 1886; Vol. VI., 1888, and First Annual Report, 1890. These publications have made him an authority on the subjects

discussed, and have materially assisted in the development of oil and gas resources, not only in Ohio but elsewhere. His other publications on the clays, coal, and other resources of the state are no less valuable, and it may be safely said that no state geological survey has ever been of more advantage to the people of the state than the Geological Survey of Ohio under Professor Orton.

R. A. F. PENROSE, JR.

Geological Survey of Ohio, Vol. VII., *Palæontology*.

A valuable addition to the palæontology of the state of Ohio is included in this volume. Professor R. P. Whitfield publishes in chapter III. a series of papers on the faunas of the Lower and Upper Helderberg, the Marcellus shales, the Huron and Erie series, the Maxwell limestone (equivalents of the St. Louis and Chester beds of Illinois) and the Coal Measures. Following this are articles by Professor C. L. Herrick, Dr. A. F. Foerste, and Mr. E. O. Ulrich, on various special groups (Lower Silurian, Clinton and Waverly). Chapter VI. by Professor Claypole and A. A. Wright describes the fossil fish of the Ohio shale and is a continuation of Professor Newberry's work in this line. With the exception of chapter VI., the descriptions here given have been for the most part already published elsewhere, so that particular comment seems to be unnecessary. Their especial value here consists in the fact that they have now been collected together, and by the generosity of the state become readily accessible to a much larger circle of scientific readers. The paper on the Clinton is a distinct addition to the somewhat scanty literature of this formation. Twenty-nine forms are found to be common to the Clinton of Ohio and the original Clinton of New York state, though the exact parallelism is not altogether clear, and on the other hand an examination of the cuts shows a strong resemblance, or indeed an identity of many of these Clinton with well-known Niagara types. Thus *Calymene Vogdesi* would seem to present no tangible points of difference from *C. Blumenbachi* and *Illænus madisonensis variety depressus*, as figured, could with difficulty be distinguished from *Illænus insignis* as figured by Hall (Twentieth Rept. N. Y. Mus., Pl. 22, Fig. 14). The author has, however, taken much pains to point out differences and likenesses of allied forms, and often frankly acknowledges the difficulties of separating Clinton and Niagara types.

E. C. QUEREAU.

Report on Surface Geology. By ROLLIN D. SALISBURY, in Annual Report of the State Geologist of New Jersey, for 1893, pp. 35–328. Pl. 1–6, and three large-scale, folded maps.

This is the third report of progress which has appeared on the detailed studies of the surface geology and topography of New Jersey now being made by the Geological Survey of that state. The results recorded are the outcome of the field work in 1893, conducted by Professor Salisbury, who was assisted for longer or shorter periods by Messrs. H. B. Kümmel, C. E. Peet, A. R. Whitson, and G. N. Knapp. The area examined is practically the northern third of the state. Observations were confined to the records of glaciers, and to certain gravel deposits more or less closely associated with ice invasions. The order of treatment is chronological, beginning with the oldest records that have been thought to belong to Pleistocene time.

The Yellow Gravel.—The occurrence of detached areas of gravel and sand, from the latitude of Staten Island southward has been known for several years, and usually designated as "Yellow Gravel," and referred in part to the Columbia and Lafayette formations. When traced southward, the areas occupied by this deposit became larger, and are believed to coalesce finally so as to form a continuous sheet, having a wide geographical range. Along its northern margin this deposit attains a maximum elevation of nearly 400 feet above the sea, and declines gently southward. It has usually been considered a single terrane, but the report before us proves that it includes at least four distinct deposits differing widely in age. Three of these divisions have been given local names as follows, beginning with the oldest: Beacon Hill, Pensauken and Jamesburg. The fourth and youngest phase is not named.

While the more obtrusive lithological characteristics of these four terranes are similar and in a general way are expressed by term Yellow Gravel, yet careful study has shown that they differ widely in composition and that the pebbles they contain were derived from widely separated sources. The Beacon Hill gravel is characterized by the presence of yellowish quartz, chert, flint and sandstone pebbles, and by the entire absence of shale and granitic material. The constituent pebbles range up to three inches in diameter, and cobbles and moderately worn slab-shaped fragments, two feet in diameter are occasionally found. In the Pensauken which was derived largely from the Beacon Hill, there is an addition of material from widely separated sources to

the north, much of which is of such a size and shape as to suggest that ice may have assisted in its transportation, though no glaciated material has been found in it. The advanced stage of decay observed in the pebbles and bowlders of this deposit shows that it has been long exposed to the action of the atmosphere, or perhaps more properly, to the percolation of surface water. The third deposit, the Jamesburg, is markedly heterogeneous. It is more loamy than the preceding, but contains cobbles and even bowlders of large size, some of which differ in character from those of the Pensauken, and were derived from different sources; glaciated bowlders are occasionally found. An important change in geography, at least, if not in reference to glaciation, is thus indicated. The lithological characteristics of the fourth stage are not stated, but presumably they are such as would result from a working over and commingling of the material composing the three earlier deposits. It is thus evident that the lithological differences in the several divisions of the Yellow Gravel are sufficient in themselves to warrant a subdivision of what was formerly considered the record of a single period of deposition.

The Beacon Hill gravel was laid down on the even and uneroded surface of the Cretaceous. Elevation followed and stream channels were sunk through the gravel and into the marl beneath. In these channels in part, the Pensauken was deposited during subsequent submergence. In the Pensauken there are fragments of ferruginous concretions derived from the Cretaceous; these are absent from the Beacon Hill gravel, showing as do other facts, that the Cretaceous terrane was not cut by stream channels until after the first division of the Yellow Gravel was laid down. Another elevation followed the Pensauken stage, and during a subsequent submergence the Jamesburg was spread over the channeled surface of the second deposit. The fourth stage of submergence was of minor importance; its records are confined to the seaward margins of the region, and vary in elevation from twenty-five to forty-five feet. This is evidence of a moderate submergence subsequent to the Jamesburg stage, or may possibly represent a halt in the process of upheaval that closed that time of deposition. Thus, by unconformities, the Yellow Gravel is shown to belong to at least three periods of subsidence, separated by intervals during which the region was elevated and exposed to erosive agencies.

The Beacon Hill gravel is known from its stratigraphic position to be post-Cretaceous. While evidence of its precise position in the

geological column is lacking, there are reasons for believing that in part at least, it is Miocene. The last subdivision of the Yellow Gravel is thought to have been either contemporaneous with the last glacial epoch or more recent.

In reference to the length of time represented by these deposits, it is stated that the interval between the first and second divisions was probably much longer than the time which has elapsed since the second; and that the interval between the second and third stages was longer than the time since the third.

The relation of the later phases of the Yellow Gravel to Pleistocene glaciers, and the probability that the Jamesburg formation at least was deposited in part through the agency of floating ice, and possibly in the vicinity of glaciers, are discussed and the weight of the evidence indicated. The presence of a great variety of rock materials, including large bowlders, in the Pensauken, and the occurrence of that deposit beneath "extra-morainal glacial drift," seems to suggest that there may have been a time of glaciation of older date than the earliest evidence of glacial work otherwise recognized in the region studied. The absence of glaciated stone from the Pensauken, makes it impossible to connect this formation with the ice with any degree of certainty.

Extra-morainal drift.—The true nature and significance of certain detached areas of much weathered morainal material, south of the great terminal moraine that crosses northern New Jersey, has been the source of controversy, but the mass of evidence presented in the report before us must silence opposition, as the glacial origin of the material referred to is placed beyond all doubt. The distribution of this extra-morainal drift from the Delaware eastward, for about halfway across the state, is accurately mapped, but its extension in the lower country to the eastward is indefinite and seemingly indeterminate. Its maximum extent south of the terminal moraine is twenty-two miles, and the area more or less completely covered by it, about 450 square miles. This older drift occurs in detached areas and bears evidence of marked decay and extensive erosion. A large part of the region it once covered retains only scattered bowlders to show the nature of the former covering. The southern limit of the ice during this earlier invasion is approximately indicated on a large scale map which also presents much additional data concerning later glacial deposits.

The care with which the distribution, character, weathering, erosion, etc., of the extra-morainal drift has been studied and the amount of

evidence on which the conclusion as to its nature and age are based, may be judged to some extent by the fact that fifty pages are devoted to a detailed record of observations.

The terminal moraine.—Next in order in this historical study of Pleistocene of New Jersey come fresh observations concerning the great terminal moraine that crosses the state. The course of this prominent topographical feature has been re-traced and mapped with care, and the characteristics of its varied features described and their origin discussed. Attention is directed to the influence of pre-glacial topography on the trend of the moraine. Where the country is low and offered few obstructions to the advancing ice, the moraine extends farther south than on higher and more rugged areas. The same relationship between the trend of the moraine and the character of the antecedent topography, appears also when minor features are studied. Thus at the crossing of every pre-glacial valley the moraine bends southward showing that the valley facilitated ice movement. Local elevations on the other hand caused the moraine to recede from its normal course.

The moraine is a conspicuous topographic feature, especially when seen from its outer or southern face. In places it rises abruptly to the height of 140 feet above the over-washed gravel fringing its outer margin. Its inner or northern slope is not strongly pronounced and frequently merges with gentle gradations into the drift-covered country that it borders. The distinction between the moraine as a topographic feature and the topography of the moraine is emphasized. Special features in the relief of the moraine and characteristic examples of morainic topography are described and illustrated by sketches.

The characteristics of both the outer and inner margins of the moraine are described in detail, and many observations recorded in reference to its width, depth, and the character of the material of which it is composed. Its course and width, and the extent of the over-washed apron of gravel bordering it on the south, are shown on a large-scale map of the state.

Drift deposits made under the influence of stagnant ice.—The origin of certain gravel terraces with irregular margins and projecting spurs, occurring on the sides of valleys, is explained on the hypothesis that the centers of the valleys where they are found were formerly occupied by stagnant ice, and that sand and gravel were swept into depressions bordering it on either side, and into crevasses in its margins. A *mold* of the ice, as it may be termed, was thus formed. When

melting occurred, the gravel and sand were left in terraces with irregular valley slopes, corresponding with the irregularities of the ice against which they were deposited.

These terraces, and especially their projecting spurs, formed by the filling of crevasses, present many of the features of kames; they are therefore named *Kame Terraces*. This is a welcome addition to topographic nomenclature. The irregular outer margins and projecting spurs of kame terraces seem to make them specifically distinct from similar deposits formed on the borders of moving glaciers.

Drift phenomena of the Palisade Ridge.—The records of a detailed study of the glaciation of the Palisade trap ridge on the west side of the Hudson, occupies sixty-seven pages of the report. This long, even-crested monoclinal ridge, rising from 200 to 400 feet above tide, was crossed obliquely by the ancient glaciers and offered a stubborn resistance to their advance, as is shown by its worn and striated surface. Many measurements of the direction of striæ are shown on a large-scale map, which indicate that the average direction of the ice movement was about S. 44° E. In some instances there are two series of striæ on the same surface, as is common in many formerly ice-covered regions. The most probable explanation of these double records, according to Salisbury, seems to be that during the advance and again during the retreat of the ice, there were variations in its direction of flow, owing principally to the expansion and contraction of the glacial lobe under which the Palisade ridge was located.

All of the peculiar markings known to have been made by glaciers on rock surfaces, such as striæ, grooves, chatter marks, disruption gouges, etc., were discovered on the Palisade Ridge, as well as perched bowlders, *roches moutonnèes* and other similar records. The till covering a large part of the ridge presents interesting features, among which are blocks of sandstone, at elevations from 300 to 500 feet above the ledges from which they were derived, and illustrating the lifting power of glaciers.

The borders of the Palisade Ridge, especially on the northwest—the direction from which the ice came—are in places heavily encumbered with stratified gravel and sand, which record the abundance of the drainage from the melting ice.

A yellow loam occurring in detached areas at various elevations on the Palisade Ridge is the subject of several ingenious hypotheses. The most plausible explanation of its origin seems to be that it was accumu-

lated on the ice, partially as dust, and left on the surface of the till when the melting occurred. The fact that superglacial material, especially on stagnant ice-sheets, is subjected to many changes of position and experiences many falls, and is thus broken, and that it is also disintegrated on account of changes of temperature, might, it seems to the present writer, be cited in connection with the hypotheses suggested in reference to superglacial origin of the loam.

Lake Passaic.—The conclusion that a large glacial lake formerly existed in the drainage basin of Passaic River, in north-central New Jersey, was advanced by Professor George H. Cook, the late state geologist, in his annual report for 1880. The strength of the evidence on which this conclusion was based has since been questioned, and several geologists who have visited the region have doubted if Lake Passaic, as the old lake was named, ever had an existence. This subject has been restudied by Salisbury and Kümmel, and so much consistent evidence advanced that the former presence of the water-body referred to must not only be accepted, but given a prominent place among examples of ice-dammed lakes of the nature of Merjelen Lake, Switzerland, the first existing example of the type to be studied.

The trap ridges of central New Jersey, rising above low-lying areas of Newark sandstone and shale, have such a form that an ice-sheet advancing from the north would occupy the depressions through which the drainage escapes, and thus shut off a considerable basin from free discharge to the sea. This in general was the history of the origin of Lake Passaic. The evidence furnished by lacustral deposits, terraces and other shore features, as well as by the position of the great terminal moraine, although indefinite at times and seldom pronounced, is, on the whole, sufficient to prove the former presence of Lake Passaic and to admit of the mapping of its shores. Like most lakes held by ice dams, the glacial lake of New Jersey had a varied history, several chapters of which have been deciphered. During its maximum it was about thirty miles long from north to south and ten miles broad at its widest part, and over 225 feet deep.

Since the lake was drained, the region it occupied has undergone changes in elevation and the old shore lines are no longer horizontal. An increase in elevation from south to north of sixty-seven feet in thirty miles, or at the rate of 2¼ feet per mile, has been shown to exist. These changes are supposed to be due to a re-adjustment of isostatic conditions after the disturbances produced by the weight of the Pleistocene ice-sheets.

This admirable report of progress, covering nearly 300 pages and accompanied by three large-scale maps and dealing with the surface geology of perhaps one-third of New Jersey, establishes a precedent that those in charge of other geological surveys will do well to follow. It will no doubt be a surprise to many who read the topographic history of New Jersey as interpreted by Salisbury, to learn that in the surface features of the land there is preserved a record that is fully as interesting and instructive as the history of past faunas and floras, which for a long time was considered the special field of the geologist.

Geologists and geographers alike will await with interest the appearance of the final monograph of the surface features of New Jersey, which the reports of progress already issued lead them to expect.

ISRAEL C. RUSSELL.

Bulletin of the Geological Society of America. Vol. VI., pp. 103–140; Pl. 1. *Reconstruction of the Antillean Continent.* By J. W. SPENCER, A.M., Ph.D., F.G.S. (L. & A.). January, 1895.

In this paper the author arrives at some very striking conclusions concerning the elevation of the Antillean island during Pliocene and early Pleistocene times. The deep depressions, which cross the continental shelf and which are believed by the author to be drowned valleys, furnish him data by which to estimate the amount of such elevation. Between Cape Hatteras and the Bahama Islands four clearly marked depressions cross the continental plateau. Three of them are in line with rivers of the coastal plain. These fjords can be traced for distances between 200 and 300 miles, and into water 12,000 to 14,000 feet deep. One of them sinks over 5000 feet below the level of the submerged plateau and is comparable to the Grand Cañon of the Colorado. Between the Bahama islands are depressions traceable for distances up to 350 miles, and from depths of about 2000 feet into waters 10,000 to 14,000 feet deep. In the Gulf of Mexico similar submerged valleys exist, and in most cases they are closely related in position to existing rivers. They are traceable into water 10,000 feet deep. Their bottoms sink from 800 to 3000 feet below the top of the valley sides, and they are several miles in width. Other fjords occur off the coasts of the West Indies, and around the Caribbean Sea, some of which are traceable into depths of 12,000 feet.

The author concludes that these are land valleys which have been

greatly depressed. He bases his conclusions, (1) upon their general resemblance in contour to land valleys, and (2) upon their direct connection (in most cases) with existing rivers, save where such connection has been manifestly obliterated or obscured by recent coastal deposits. In many respects these depressions resemble land valleys, and the author's conclusion has a strong basis of probability. The following consideration may, however, be urged against his view. If these depressions are drowned land valleys, the soundings ought to show the existence of great deltas at their mouths. The author makes no mention of such deltas and the inference is that they do not exist. Their absence, so far as known, is a serious objection to the author's view.

The logical inference from Mr. Spencer's conclusion respecting these fjords is that the land formerly had a much greater elevation than at present. Assuming that the depth to which the mouths of the fjords are now submerged is nearly the exact measure of the former elevation of the continent, and making a small allowance for foldings and amplified marginal depressions, Mr. Spencer concludes that this elevation was not less than 8000 feet along the northern shore of the Gulf of Mexico, about 12,000 feet in the vicinity of Yucatan, 10,000 or 12,000 feet for the Greater Antilles and nearly the same for the southeastern margin of the continent. The soundness of this assumption will be considered later. Waiving for the moment this point, let us note the author's conclusions.

In the West Indies Mr. Spencer has found two series of deposits which he correlates with the Lafayette formation and with the older Columbia series. To these he gives the names Matanzas and Zapeta, respectively. They are separated from each other by strongly marked unconformities. The Matanzas is likewise separated from the upturned and deeply eroded Miocene beds by a great unconformity. Combining the data furnished by these deposits with the quantitative element furnished by the fjords, the author reaches the following conclusions as to the oscillations of the land. From an elevation toward the close of the Miocene much lower than at present, the land in the Pliocene was elevated according to location from 8000 to 12,000 feet higher than at present. The close of the Pliocene saw the Antilles and the neighboring parts of the main land 100 to 1100 feet lower than at present. During this depression the Matanzas limestone was formed. This subsidence was followed by a re-elevation in early Pleistocene times, probably as great as that of the Pliocene. The fjords crossing the

continental shelf were first excavated during the Pliocene, and then re-excavated — so far as filled during the Matanzas depression,— and deepened during the Pleistocene elevation. Later in the Pleistocene the land sank to a level 25 to 500 or 700 feet below the present elevation and the Zapeta loams and gravels were formed. Minor oscillations, not yet well worked out, have since taken place.

The most important conclusion of this paper, *i. e.*, the amount of the elevations, is based upon the assumption that the continent stood as much above sea level as the fjord bottoms are below it, less some correction for unequal subsidence of the continental area. Although granting that a correction should be made for unequal subsidence, the author seems, so far as appears from his paper, to have practically neglected this point in his calculation of the former elevation of the land. The amounts of elevation which he gives for the various regions are almost as much as the amounts by which the fjord bottoms lie beneath the sea level. It seems possible to account for the depths to which the mouths of the fjords are submerged, without assuming that the continent stood at such heights.

Grant that the elevation was sufficient to permit streams to cut valleys across the continental shelf hundreds of feet deep, and in one instance, at least, to excavate a cañon comparable to the Grand Cañon. It is probable that subsidence, once started, would be greater along the edge of the continental shelf than further inland. This would naturally follow on the doctrine of isostasy from the loading of the outer part of the continental shelf by sediments, deposited as the shore line advanced inward. It seems highly probable that the subsidence would be of the nature of a seaward tilting of the land and a deepening of the ocean basins.

Such differential motion along lines normal to the coast would increase the gradient of the bottoms of these buried channels. Before the author's hypothesis of practically uniform subsidence along normals to the coast can be accepted, it is incumbent upon him to show that the above hypothesis of subsidence with great tilting is inapplicable to the case in hand. So far as known to geologists, all epeirogenic movements are in the nature of tiltings and warpings rather than rigid uniform changes. If the subsidence were uniform or varied only along lines roughly parallel to the coast, the buried channels would retain practically the same gradient as they had when land valleys. A rough means of testing this hypothesis is thus at hand.

If the gradient of the fjords is much greater than that of land valleys, which most closely correspond to them in width and depth, the conclusion that the land "stood as high as the fjords are deep" would seem not to be warranted. Moreover, if the subsidence along normals to the coast was equal, the gradients of the bottoms of the fjords would be less than the gradients of the rock bottoms of the rivers, of which the fjords are continuations. For the gradient of a valley is always greater nearer its head than in its lower part, if the rocks are not greatly different in the two parts of the course. Further, the rivers of the coastal plain meander in wide valleys, now filled to a considerable depth with alluvial deposits. The width of these valleys compared to their depth, where known, shows that they were well advanced in the cycle of erosion, and that their gradients must have been comparatively low. If this be true for the valleys of the coastal plain, to a much greater degree must it be true for the submerged parts of these valleys across the continental shelf. From what is known of the dimensions and contours of these fjords, a low gradient can be confidently predicted, unless the continental shelf has been tilted seaward.

From the data given, the gradient of a few of these fjords can be estimated. The Bahaman valley has an average fall of twenty-four feet per mile for 350 miles; the Floridian, of twenty-five feet per mile for 400 miles; the Cazones, of seventy feet per mile for seventy-five miles, and the Altamahan, of nineteen feet per mile for 300 miles. These gradients are much greater than those of corresponding land valleys. The Grand Cañon of the Colorado has an average fall of less than eight feet per mile for 284 miles.[1] Judging from borings in the alluvium deposits of the Mississippi at New Orleans and Memphis, the rock bottom of the river between these two points has a gradient of but little more than two feet per mile. Since it is not certain that these borings reached the deepest part of the valley at their respective localities, the gradient may be more than this; it may, however, be less. But in spite of this element of doubt it is absolutely certain that the gradient is much less than that of the submerged valleys. The gradient of the fjords, considered in respect to the size of these valleys and compared with the low gradient of land valleys strongly favors the hypothesis that the subsidence was much greater remote from the present coasts, than it was along the shore. It cannot, therefore, be safely concluded that because the mouths of these fjords are now submerged to depths from 10,000 to

[1] DUTTON: United States Geological Survey, Monograph II., p. 240.

12,000 feet or more, that the whole Antillean continent stood an equal amount above its present level.

The bottom of the fjords, particularly the landward portion, have probably been somewhat filled with sediments. The gradients as calculated from the soundings may be too great. But it is not probable that the possible error from this cause can bridge the discrepancy between gradients of the fjords and those of similar land valleys. The facts given by Mr. Spencer prove a greater elevation of the continent in Pliocene and in early Pleistocene times than at present, and a lower level at the end of the Pliocene and later in the Pleistocene. It may be fairly questioned, however, whether they prove the great elevation above the present level which is claimed.

HENRY B. KÜMMEL.

Elements de Paléontologie. By FELIX BERNARD, Paris, 1895; 1146 pages, 606 illustrations, Baillaire & Son.

A new palæontology bringing up to recent date the more important results of work in this field will be welcome to many. It includes a phytological as well as zoölogical portion, though the *Invertebrata* are more fully treated than the remainder. Morphology and classification are treated with especial fullness, though the latter is carried down only as far as the family or, usually, the genus. The phylogeny and embryology of groups is also given in summary at the close of the different sections. The sections on the brachiopods and the crinoids are especially well developed, and the introductory chapter of the book in which the scope of palæontology and its relations to other sciences is discussed will be found of especial interest.

E. C. QUEREAU.